INTERVIEWEE: Kurt Lehovec

INTERVIEWER: David C. Brock

LOCATION: Williamstown, Massachusetts

DATE: 21 August 2007

PROJECT: CHOE (Project # 8271)

BROCK: Would you like to – one place we could begin would be to – I know that you attended the Charles University in Prague from ’36 to ’45 I believe. Would you like to maybe spend a little bit of time talking about your education before that?

LEHOVEC: Exactly. This is exactly how I wanted to do that.

BROCK: Great.

LEHOVEC: This is a brief review and oversight – a review of my life history as a scientist and oversight about my contributions. I was born in Czechoslovakia in 1918, the son of an officer, Czech officer, and a German speaking Czechoslovakian mother. My parents soon divorced and I was brought up by my mother with a one year older brother. My mother sent us to German speaking schools in Czechoslovakia and I attended the Charles University in Prague which had two branches, a Czech branch and a German branch and I attended the German branch.

My interest was mathematics, but when I was ready to start a thesis, Hitler took over the rest of Czechoslovakia and all my mathematics professors had been Jewish and they all disappeared. I think they left. I know they left. They were not [________] [00:02:41]. They left in proper time and there was no senior mathematics professor. And then I started chemistry, but within a few months, a physics professor from Germany came, professor Gudden [00:03:06], who was a foremost man in Germany on photoelectric materials and photo-electricity and semiconductors. And I started my thesis on infrared detection by leadselanide. So I was exposed to all the appropriate background, namely evaporation of the material, the action of the lead to be the selenium vapor, doping, electrodes by evaporation and testing of the spectral distribution and to the dependence on light intensity, with other words, the full semiconducting background I had then already 1939.

But as soon as I got my PhD, the Germans drafted me in the army and I was attached to the first [________] [00:04:41] cavalry division and sent to Russia to fight there and had a very interesting brief period in Russia first with the advance of the German army and then the Siberian troops, the collapse of the German frontier, the retreat, coming to a village where the general staff was all killed, throat cut, only dead people. I caught a horse which was around a sled, went to the officer's – I had no [________] [00:05:22] whatsoever, to the officers' luggage, found a fur coat and traveled separate from the German army and traveled alone 40 below zero, nothing to eat. Russians would have killed me if they find me. The Germans, I had left them. Wonderful experience and I was so close to God at night, the stars and everything quiet. Well anyway.

BROCK: May I ask just a few questions to follow up on some of these points that you just made? How did you – could you describe your pre-college education? Did you go to like a local gymnasium or something like that?

LEHOVEC: Okay. The high school in Czechoslovakia had two parallel branches. One was called gymnasium which prepared people mainly for medical and they had Latin and so on. [00:06:19] And the other was a Real Schule [00:06:25], which I attended, which was more toward technical things. But I took private classes during my attendance of the Real Schule in Latin because I was not sure yet what I wanted to become professionally and I appreciate it very highly because Latin has some very interesting sentences like, "Ipsa loc viture," [00:06:56] legal sentences are common. So I was very happy for that. Alright.

So now I then after my couple of days and nights alone with a horse and a sled and nothing to eat and nothing to feed my horse, I make it back to the German troops to get food and we broke through the Russian encirclement and we retreated and spent a new defense line. It was Christmastime. And then I became very sick. I got what is called the Rocky Mountain Yellow Fever, which is a deadly disease and after I survived, I was taken back to Germany for recuperation and they sent me to an officer's school in Ploun, Saxonia [00:08:07] and it was a few days before the graduation and I would have become a lieutenant and sent back to Russia and they invited me to the secretarial office and threw papers in front of me and they said, "Your travel orders." And I stammered, "First the inspection in a few days."

"Can't you read, you stupid?" So I picked up the travel orders, "Dismissed from the army. Go back to Prague to the university. Work on research." Da, da, da, da. My roller coaster life from starting at the bottom again, I got to the top.

BROCK: Had they sent you to the front as just an infantry soldier?

LEHOVEC: No. At first I went to the First Eastern Prussian Cavalry Division so I was on horses.

BROCK: Okay.

LEHOVEC: And they are very interesting stories. I, with a Czech name, with glasses, with a PhD in physics and all the corporals were country cowboys practically. I had to clean horses. I had to walk around and around on the [________][00:09:29] sinking in almost to the top of the boots. For hours I had to run around shouting, "I am stupid. I am stupid. I am stupid." And the corporals were sitting there laughing and applauding and I hadn't done anything, just to amuse them. So you know how I loved the German army.

BROCK: It seems – it's surprising that they would send somebody with such technical ability.

LEHOVEC: Exactly. And what happened was that the frontier for the Germans in the first couple of months against Russia was so successful that the frontier shifted very quickly into Russia and they made us walk back. They didn't need us as reserves right away. So they say, "You can walk." So we walked. I walked through half Russia and never caught up with a troop and when I caught up, the cavalry division was retracted to Germany to become motorized. And they said who has a drivers license come back to Germany and be motorized, and of course, instead of fighting, 'cause this was highly desirable, but I had no driver's license, but many of the other soldiers who had no driver's license said, "We have one." What the hell. They sent us back to Germany and they will teach us. What's the big deal? But I never lied in my life. I have never said a lie in my whole life. Perhaps my mother taught me lying is weakness and I didn't want to be weak. So I never lied. I was always, even so I could have great advantages by a lie, I never did it.

Well anyway, so back to Prague to Professor Gudden and I was assigned a project on selenium rectifiers and it was funded by the [________] Deutsche [________ ________] [00:11:42] in Nuremburg. And there came a great calamity that the selenium rectifiers which were used for charging the batteries of tanks and so on, the all deteriorated suddenly in the field and it was a big disaster. And I discovered the reason by luck.

What I did was that the selenium rectifier is a polycrystalline [00:12:24] selenium film and then they spray on a rectifying electrode. And this is a low melting point alloy having bismoot [00:12:42] among others and other things, tin. They spray on and it had also other ingredients, one being thallium and I suspected that the deterioration is caused by one of the ingredients in the electrode so I pressed little stencils like this from selenium and I evaporated the electrode on both sides and I applied voltages and heated it and I thought what will be the potential distribution [________] [00:13:29] the rectifying contact or the potential drop will be at the contact. If it's [________] [00:13:36] there will be a linear distribution. So we will see.

And to my great surprise, I found with thallium that – see I applied 100 volts, that it stayed at zero volts a couple of millimeters into the sample and then it jumped to 100 volts and stayed at 100 volts. I had, in the middle of the sample, suddenly a higher resistance layer. And that happened with thallium and I could move this by heat treatment and I applied voltage, I could move it.

BROCK: Move this area of the –

LEHOVEC: Of this, where the jump was. My first, of course, when I first saw it, I was sure there was a crack in the sample. So there was a crack simply there. I took another sample, the same thing and then I started moving it. And this is my first publication is on that.

BROCK: And what was the mechanism of that? What was behind that odd behavior?

LEHOVEC: Well, I didn't understand the mechanism fully. I only knew that if there is a lot of thallium, it is conducting and if there is no thallium, there is conducting and at a certain concentration of thallium, there is – a higher resistivity develops. And I published a paper and my professor Gudden, my director who was nothing than a politician at that time and he was a Nazi [00:15:19] official, he came with the SR [________] [00:15:24] uniform once a week with the insignia to the left. You can imagine how he loved me with a Czech name and so on, but then he respected me because I had been in Russia fighting there. He – published with him even though he didn't contribute a damn thing.

BROCK: This was the same man who you had worked with before?

LEHOVEC: Yeah right, with whom I made the thesis and he got me back from the frontier.

BROCK: That's what I was wondering.

LEHOVEC: Yeah, he needed – he got research contracts and he needed people to do it so I was one education by him in [________] [00:16:07] so he got me back.

BROCK: Right.

LEHOVEC: And so I had very – I was – we came overnight to [________] [00:16:21]. I was invited to Nuremburg to the Sueddeutsch Apparate Fabrik and I came there. It's a big [________] [00:16:28] by the Americans. It's another thing I survived. It's a very old station in a bunker I waited for the train coming through, take me out and the train didn't stop and rushed through and the bomb was already – I hear, "BBBBB", and I saw them and I quickly went as the last man into the shelters and then it stopped. And so when I come out, everything destroyed.

Well anyway, these are some of the sideline stories. So I became a hero by Apparate Fabrik and – but then came the Russians approached Czechoslovakia and they approached

Prague and Prague was occupied by the SS, German SS and there would be fighting, street fighting and the – there was an uprising by the Czechs in the last moments before the Russians came and I can tell you stories about it, how I got out. Let's not go into details. But anyway, I figured since I had been a soldier against Russia, it was advisable not to be present when all this happened.

BROCK: Russian soldiers – yeah.

LEHOVEC: I was sure that, of course, the Germans would lose and I thought after a couple of months, it would be the old Czechoslovakia. So I took my bathing suit and my tennis racket and my bicycle and I pedaled to the west where the Americans already were and I thought I have a nice holiday in the American occupied Czechoslovakia and when everything is quiet, I bicycle back to Prague and it never happened.

BROCK: Did you not fear what would happen to you in going into the American occupied area?

LEHOVEC: No. I was a civilian and – but actually horrible things almost happened to me there, but I don't want to go in details with them. I want to skip this particular part. The end was that as the Americans left, I moved out with the Americans to Germany and found myself in Germany, penniless with a bicycle, a tennis racket and a bathing suit. And I worked for the farmers and slept in their barns and made my way to Nuremberg actually to [________] [00:19:23] house of Nuremberg where the Sueddeutsch Apparate Fabrik had a research lab when Nuremberg was bombed. So I went there to this lab and but the lab very soon closed down and –

BROCK: Did you work in the lab for a time?

LEHOVEC: Yes, well there was no work really going on. I came here and I said, "Here I am from Prague." They all knew me. We were all sitting around and nothing happened and then they closed the lab and I became a private teacher on a castle where the owner couldn't send his children to school because he had no gasoline and so it was a nice intermission and when that stopped and he got gasoline, I became, for a brief period, a high school teacher in Zwieback near Nuremberg and –

BROCK: Was the war over at that point?

LEHOVEC: Oh yes, all the war was – when I left Czechoslovakia with the Americans, the war was over.

BROCK: The war was over. Okay.

LEHOVEC: Yeah, yeah. No, no, there was no fighting, no problems of this sort.

BROCK: Yeah.

LEHOVEC: Then telephone, no mail, no transportation, no regular transportation and I got – but so the many people migrated all over Czechoslovakia, fugitives and so on and somebody dropped in at my high school and she came from Northern Germany from the British zone and she brought me a message by a scientist, Dr. Koch [00:21:17], who worked on selenium rectifiers, had worked and he worked now for the British and he [________] [00:21:27] get me a message, the Americans are interested in me. And I was so excited I jumped on a train and the train was so full that people were reach in and out through the windows and they lost their shoes and things out. But I managed to go the whole night through to northern Germany to find out and to visit Dr. Koch and to see if the Americans are interested.

BROCK: Now how – he had known –

LEHOVEC: He worked for the British secret service exploiting technical stuff the Germans did.

BROCK: He was a German himself?

LEHOVEC: He was a German himself, yes and I knew him. He worked on selenium rectifiers too in Germany at the time.

BROCK: So you had met him around when you solved the problem with the selenium rectifiers or –

LEHOVEC: I don't know whether I met him after this or not, but anyway, so I went back to my high school and one day a jeep pulled up and they took me out of class and an American officer said, "Would you like to come to the United States?" And I said, "Yes." And he said, "What are your conditions," because this was a project paper clip where Wernher bon Braun and all the rocket people came. And he asked me, "What are your conditions?" And I said, "None."

BROCK: Why were you – what was in your thinking about what that possibility meant for you? Why were you interested in going to the United States?

LEHOVEC: Well, first of all, I knew that they would bring me over to do research and I had, as a high school teacher, I already did research there to and as a matter of fact, one of the things I created as a high school teacher in 1945, late 1945, no beginning 1946, I discovered the mechanism of the photovoltaic effect, solar cells. I discovered it. They had solar cell selenium rectifiers were known commercial product – not rectifiers – selenium photocells for light meters in photography and so on. But nobody understood the mechanism and I published in a German journal which came out, [________] [00:24:42]. I published the how solar cells work.

BROCK: About the photovoltaic effect.

LEHOVEC: The photovoltaic effect. Well anyway, so –

BROCK: And that was a theoretical paper?

LEHOVEC: A theoretical paper. Simply, exactly what I say it is that in selenium rectifiers you have a space charge layer generated by the rectifying electrode in the semiconductor. The space charge layer is in the semiconductor so there is an electric field and when you illuminate with the appropriate light, you create electron holes and the electric field separates them and voila, this is the effect.

BROCK: Alright.

LEHOVEC: And as simple as that, but nobody gives me credit for that. They all give credit to Bell Labs who was supposing they did it.

BROCK: Are they working at the same time?

LEHOVEC: No. Much later, but they worked – did it on silicone so – but anyway. So it took them still a couple of months and a very interesting intermission there. I was brought to an army base and was shipped to America and after two days they dismissed me. "Go back. We don't need you yet."

And I came back and the whole town of Weissenburg was brimming. I go to the United States and here I come a couple of days later, "Oh that was a short visit." And they – I could see the hate of people and well anyway. But then again after a couple of months, they called me, put me on a boat, brought me to the US Signal Corps in Fort Monmouth, New Jersey and I never had English in school. We had Czech, German and French. And – but I had picked up, of course, at university, a little bit of English.

And as a matter of fact, I taught when I was at this castle and I taught the children who knew nothing about English, I taught them English without ever having been taught English. But they didn't – but anyway. So I came and in my broken English I asked at the US Signal Corps, "What can I do for you?" And they said, "Do whatever you like. We can use everything." An institute of advanced study? How can my life change like that?

Well, and of course my first work at the Signal Corps was for – on selenium and I wrote a very important paper which you might perhaps make a note of it.

BROCK: Yes.

LEHOVEC: I discovered that if you apply the voltage at the selenium rectifier for a certain period of time and then [________] [00:28:20] which means the electrode and selenium has changed, but slowly drifts back with the old value. So there is a time lag effect of recovery. And I ascribed that to surface states at the boundary between the electrode and the selenium and I thought it was as though then one can, by a transfer in electrode and shining light on it, one could charge or discharge the surface states. And I wrote a paper. Perhaps I should give you the numbers of my publications and I should give you the number of it, my number of publication. First of all, the paper for the thallium with my professor is number four in my list of publications. Then the photovoltaic effect is number one in my publications.

BROCK: And you've republished that in English?

LEHOVEC: Yeah right and actually number one is a brief note. Number three is a longer German paper on the same thing and then I published it and then number five is again in German the same subject and then when I came to the United States, I published it in a physical review, this is number six.

BROCK: And that was in '49, was it?

LEHOVEC: This was in August 1948.

BROCK: 1948.

LEHOVEC: Yeah. Physical review 74, number 74.

BROCK: Right.

LEHOVEC: And the publication really of the [________] [00:31:11] of selenium rectifiers after voltage pulse is number ten, but the important paper which I published in Nature, the British journal Nature, this is a very high profile journal.

BROCK: Sure.

LEHOVEC: It's number 12, Origin of Time Lag Effect in Selenium Rectifiers. And this is –

BROCK: That's 1952, is it?

LEHOVEC: That is 1951, March 1951. And this is the – one of the first things about surface states. Okay.

BROCK: I want to ask you [________] [00:32:05] interrupt the flow.

LEHOVEC: Very good yeah. Very good yeah. Very good.

BROCK: Your thesis work in Prague about using leadselanide as an infrared detector, I was just curious about in the late 1930s, the context in which physicists were looking at semiconducting materials. Was it mostly connected to things like the photovoltaic effect or photoelectric effect? Was that a prime reason that people were looking at semiconductor materials or what can you say about physicists looking at semiconducting materials then?

LEHOVEC: Well, I can say that the God, with respect to solid state science in Germany, was R.W. Pohl.

BROCK: P-O-H-L.

LEHOVEC: P-O-H-L. Yes. And he had worked on alkali-halides, the so called color centers in alkali-halides that when you will use them and so on and it forms that and the photo effects in this and his principle student was Gudden, B. Gudden was his main student – main professor who came from this school. And he worked on photo effects in semiconductors in nonmetallic solids and there was a primary photo effect and a secondary photo effect. The secondary photo effect generates centers which are essential like doping centers which cause then the current to flow because of the doping. The primary photo effect just generates free carriers [________] [00:34:26]. So he wrote a book, Photoelektrische Erscheinungen [00:34:34]. Gudden wrote the book which was a foremost book. And then of course, in the war, they worked on things in Gudden's lab. They worked on other things such for instance an image changer, [________] [00:34:56] bundler that you put in the night vision things and then you see, what we have now here. We worked on that. Not I.

BROCK: Using semiconductors to detect the infrared?

LEHOVEC: Yeah right. They had a semiconducting [________] [00:35:16] and they illuminated it with the infrared light and then, like in a television tube, the electrons coming out from this [________] [00:35:29] form on the screen a visible image. We did that already in Prague that time. And when I say we, I didn't do it, but Gudden's people did it. And so I was –

BROCK: Turning to the Signal Corps, when you arrived, could you tell me a little bit about the Squire Laboratory and about the Fort Monmouth and just what the – set the scene and what was going on?

LEHOVEC: Oh yes. That is a very pertinent and interesting question.

BROCK: Let me just check my battery level here. Great. I'm just gonna do one thing real quick.

[END OF AUDIO, FILE LEHOVEC 1.1]

BROCK: Great. It's going again. Let me just put this a little closer to you.

LEHOVEC: I had – first of all, I had several, three, laboratories. One was Fort Monmouth where I worked. Another was Camp Evans at Belmar, New Jersey, which is about ten miles south of Fort Monmouth.

BROCK: Okay, so in northern New Jersey.

LEHOVEC: I will be associated with Belmar, therefore it's important. And then there was a third one, Camp Cole where I never was until [________] [00:00:37] presumably be with circuitry, but I never was there. So was with the Squire Lab. It was called the Squire Lab in Fort Monmouth and the commanding officer was Colonel Young and it had different branches and one branch was the component and material branch and in this branch had a section, the micro-optical section.

BROCK: Micro-optical?

LEHOVEC: The micro-optical section of the component and material branch and I was assigned to the micro-optical section and the micro-optical section had instrumentation such as x-rays, electron microscope, ordinary microscope and their main work dealt with something had to do with batteries and I can't now think about that [________] [00:02:07]. But I was not associated with it. I was just put there with a desk and voila. So I started more work on published the photovoltaic effect and did more work on selenium essentially. And the micro-optical section had a subsection which was called semiconductors. So semiconductors were the subsection of the micro-optical section which was below material and components branch, below the Squire Lab. So I was way, way down, a nobody.

BROCK: How big of a laboratory was it?

LEHOVEC: Well, this is difficult to say. I don't know the whole laboratory, but in the component and material branch what they had mainly were people who purchased capacitors and purchased resistors. They were essentially purchase agents. They didn't do any research whatsoever. They didn't develop any components. The only research was done in the micro-optical section. But I have to go a moment.

BROCK: Oh yeah. I will just pause this. Sure.

LEHOVEC: And that is one of the –

[END OF AUDIO, FILE LEHOVEC 1.2]

BROCK: Start it again. I'm sorry.

LEHOVEC: That's fine.

BROCK: Okay, it's working now.

LEHOVEC: The head of the component and material branch was a Mr. Rogers who was essentially an administrator. The head of the micro-optical section was Ben Levin [00:00:23]. I don't know whether he was Dr. Levin or not. And Dr. Ben Levin was a Jew and I have to bring in, unfortunately, the racial aspect of it. He was a Jew and practically everybody in the section were Jewish with two exceptions, Dr. Debreadville [00:01:00] was not a Jew and the other one was – the name will come to me. The other one is very important because the other one was an anti-Semite and I was – I had no papers whatsoever, but I had to travel to various universities in the United States to supervise contracts among others [________] [00:01:30] at Purdue University. I had to supervise, to be the contact man and yeah, and the anti-Semite was Dr. Bradshaw and I am pretty sure he is dead by now so I can speak about him. And it was interesting that this anti-Semite, outspoken anti-Semite was in this section which was practically fully Jewish. So how could he survive? He survived by means of a Dr. Pain [00:02:14], and Dr. Pain was essentially a psychological advisor to the component and material branch. I mean a personnel man.

BROCK: Yeah. Right.

LEHOVEC: And Dr. Pain and Dr. Bradshaw came both from Kentucky and they knew each other and Dr. Pain protected Dr. Bradshaw and Dr. Bradshaw – and I was so – and Dr. Bradshaw was a man who traveled with me to these different places. So I became attached to an anti-Semite. In the Jewish section where Ben Levin say, "Oh these German scientists, when they come I will not even offer them a chair. They should sit on the floor." What a story! But I had – I have a long history with Jews. Many people believe I am a Jew. I look like a Jew. I act like a Jew. He is a Jew. And my Jewish mathematic professors, they all liked me and – but here I was somehow put in a strange political situation. But anyway –

BROCK: Did that resolve over time? I mean did people like Levin and other people in the department come to see you for who you were?

LEHOVEC: Well yes – no. Yeah, some of the Jews I met immediately ________ there was a Mr. Katz with whom I had a kind of personal relationship after work, going out and so on. And there was a Dr. Milton Greene, an orthodox Jew who was very nice and protected me. So only when Levin was there, really a political Jew. Well, and then came – and at this point, I run out of work on selenium rectifiers and the photoelectric effect and I felt I should look for other subjects and I made a key decision. And here I must introduce a personal aspect of it.

My loving mother had psychologically destroyed me even though she loved me and didn't wan to destroy me, but she did. And

FEMALE SPEAKER: Sorry. I had my lunch while I was out.

BROCK: Oh, thanks a lot.

FEMALE SPEAKER: Sure.

LEHOVEC: Thank you.

FEMALE SPEAKER: Here's some water.

BROCK: Oh thanks.

FEMALE SPEAKER: Choose for you?

LEHOVEC: Yeah, thank you. Thanks very much.

BROCK: Thanks. Thank you.

FEMALE SPEAKER: You're welcome.

LEHOVEC: My mother had persuaded me that I am ugly and she had brainwashed my brother and me against women and I felt I will never have a girlfriend and I didn't have any when I came to the United States. I was a virgin at thirty years and I felt so desperate about my ugliness and so on that I considered suicide and I figured there's only one thing for me to do in life and this is work. And so I didn't go out, I didn't go to movies and when I needed a new subject to work on, I made the decision I will study the entire inorganic nonmetallic solid state work since 1900.

BROCK: To review the entire literature?

LEHOVEC: The entire literature. Read all the original literature and I could have done it officially with the Signal Corps, but I needed much more time than the time at the Signal Corps. So I hired a private secretary and I went through the abstracts, scientific abstracts, took out all the papers, sent her with a copying machine to print and had her copy all these papers, thousands and thousands and thousands of them.

BROCK: Of papers?

LEHOVEC: Of papers. And I met a very interesting man. A man came to visit me, Mr. Kohn [00:08:18], from Radio Receptor company and Radio Receptor Company made selenium rectifiers and we became friends and he said he would take all these microfilms from Princeton and enlarge them if I give him and organize them and give him a copy, which of course I said yes. So I had staples and staples and staples. I rented a private room in Elway Park [00:08:56] and my landlady said she had rented me a pigpen because all these papers on the walls and so on. And day and night I studied all these papers.

BROCK: Wow.

LEHOVEC: And whenever I found something which was observed and not explained, I published a paper about it and that accounts why I have so many papers and –

BROCK: Well did you figure out a theoretical explanation for the observed defense?

LEHOVEC: Yes, on everything. For instance, number – well, and I made – then came a very important effect. Bell Lab discovered the transistor and before it was announced in the press, they invited Colonel Young of the Signal Corps to a private show and Colonel Young and I became the favorite son at the Signal Corps right away because I published. Nobody else published papers and I publish, publish, publish, publish. So Colonel Young took me on fishing trips with a high up of the Signal Corps and I was nobody way down in the micro-optical section. And when he was invited to a show at Bell Labs, he took me along.

BROCK: Were there any other people at the Squier Laboratory working on semiconductors?

LEHOVEC: No. I was the only one and yeah, they – the main work of the micro-optical section was on batteries with manganese oxide, place [________] [00:11:12] in batteries or something and they did all the work on this manganese oxide. I wouldn't call it a semiconductor.

BROCK: Right.

LEHOVEC: Well – and here is an interesting historical remark for you about the discovery of the transistor. There were, at that time, in the United Stated only perhaps six people in semiconductors in the whole United States and of course there were at Bell Labs, Schottky and Bratten and Badeen too [00:12:08], but Badeen was a more general and eventually he got a second Nobel prize for –

BROCK: Superconductivity.

LEHOVEC: But really Schottky and Bratten were there and then there was at university of Pennsylvania was a Professor Miller and at MIT were – it comes later to me – a professor and then there was Lock Horowitz a [________] [00:12:46] and he was a real, except of Bell Labs, a real main man. And I was his supervisor so to speak and before –

BROCK: He had a contract from the Signal Corps?

LEHOVEC: Yeah, all these men I say they have a supervisor, they had Signal Corps money and Signal Corps had to send out somebody to review the contract and I went out there to Purdue [________] [00:13:18] who became a professor at the University of Massachusetts. And Ralph Brie [00:13:28] had the assignment of determining conductivity in semiconductors at high fields and particularly that was Germanium what they worked on. And so if you apply a high field, you cause also heating so you cannot distinguish the field effect from the field strengths from heating effects. So in order to reduce that, the idea is to apply a very short pulse of high field so that you avoid heating. And then the other problem is, so how do you know how the field is in the semiconductor or whether you have electrode effects where when you apply the voltage at the bow of Germanium, that some voltage is – it's electrodes. So, you put two point contacts in the middle on the Germanium and when you apply the high voltage field at the end of this [________] [00:14:50], you measure the voltage drop, you measure the current which goes in and you measure the voltage drop on this too –

BROCK: Across those too.

LEHOVEC: It gives you the field. So when they did that, they observed something very unusual. They expected simultaneously with the application of the pulse to the sample a voltage drop between there, but there was a delay time. The voltage changed with a delay time from that and they couldn't understand it. And well, I could kick myself that I thought it was not fair for me to put my thinking in something which is work in progress, I mean that I come take their data and come out with a solution. I would feel bad about this. This wouldn't be fair. So I thought it's interesting, but didn't pay any attention. And actually what it was was the transistor effect.

BROCK: Yeah.

LEHOVEC: They had the transistor. They injected minority carriers from the electrode, they needed a certain time to travel there and when they arrived there, they decreased – they increased the conductivity and modified the voltage. So they had the transistor effect and didn't realize it. And a couple of months later, Bell Lab came out and Lark Horovitz who was a very ambitious man, he was a good friend of mine, he wanted me to come there and work with him. But he was so ambitious, he always at scientific meetings felt he has to compete with Bell Labs.

How many papers are given by Bell Labs as competition and now he had it and Bell Lab took it and Bell Lab got the Nobel Prize and he was so upset he told me he would have given his right arm for having found out what it is. And he got a nervous breakdown.

BROCK: After that?

LEHOVEC: One year later he died.

BROCK: Wow.

LEHOVEC: And this was a very good lesson to me in my life because when I was, so to speak, robbed of the acknowledgement of what I had discovered –

BROCK: With the [________] [00:17:38]?

LEHOVEC: I thought of Lark Horovitz and how silly to be upset by it and suffer and get sick by it and so on and so forth. So this was a very good lesson to me. So this was Lark Horovitz and I, of course, when I heard – I attended with Colonel Young the lab and heard about the transistor, I immediately understood the whole damn thing and I could kick myself because in my theory of the photovoltaic effect and I published several papers, as you know, there are four boundary conditions, one for electrons at the metal site in the bulk of the semiconductor and one for holes at the metal site in the bulk of the semiconductor. So there are four boundary conditions. And with writing, the equations with diffusion and field currents and blah, blah, blah, the differential equations. I could only satisfy three of the boundary conditions and there was an unknown boundary condition which I couldn't satisfy and in my papers, I kind of glanced over it, even in the physical review paper. And I mumbled something about a [________] [00:19:11] effect, which was some sort of a photoelectric effect in semiconductors and left it open. And what it really was was that at the bulk side of the space charge layer, the minority carriers are not the terminal equilibrium concentration in the bulk of the semiconductor. They are injected holes which their concentration extends into the bulk of the semiconductor, the transistor effect. So I had the transistor effect also and didn't realize it.

BROCK: Right, in terms of minority carrier injection.

LEHOVEC: But in a more indirect way. I had thought that at the bulk of the space charge layer, I take the equilibrium concentration of majority carriers and the equilibrium concentration of minority carriers, but it didn't work out. So I had to leave open the equilibrium concentration of minority carriers, but didn't realize it that this is simply a tail which goes beyond the space charge layer into the bulk of the semiconductor. But then –

BROCK: And you had also seen the Purdue measurements earlier so that when you went into the Bell Labs meeting –

LEHOVEC: Yeah right. Yeah then – something interesting happened. The Signal Corps, of course, knew that the transistor was big time and they knew there would be plenty of money in this field and now came the political fight. Who gets cognizance of the transistor?

BROCK: In the Signal Corps?

LEHOVEC: In the Signal Corps and Squier Labs where I worked said, "We are the material people – material and component branch. And Bell now say it, "We are the vacuum tube people. We have the vacuum diodes and vacuum tubes and the transistor is a vacuum tube replacement, so we should get it." So both wanted the semiconductor, but to just want it is not enough. They have to have somebody to do work and there's only one man in the Signal Corps who does it.

BROCK: You.

LEHOVEC: I. So both wanted me. Squier and Camp Evans and there was a big fight and finally there was a Solomonian decision. They just split me in half and I worked two days in one lab and three days in the other lab in the five days of work a week. So I came to Belmar, Camp Evans. They have a barracks, just barracks and I was given a room in a barrack and there was a desk and a chest of drawers and a chair. Now do work. So, I went to the chest of drawers, opened the drawer and there was a bunch of beautiful crystals, crystals as big as that.

BROCK: This is an inch in diameter.

LEHOVEC: And I said, “My God, what could they be? They cannot be diamonds.”

BROCK: Right yeah.

LEHOVEC: So, I took one of these crystals and went to the window and scratched glass and it scratched glass so I though it's pretty hard so I knew hardness scale of one to ten, diamond is ten, silicone carbide is nine. So I got the idea it is silicone carbide. But –

BROCK: Now was that material there because of the use of silicone for –

LEHOVEC: I have no idea how it ever – nobody could ever tell me how it got there, why it was there, who left it there. Nobody could ever tell me. It was a miracle and there are so many miracles in my life. But now one very great man, Professor Schottky, in Germany, I don't know whether you heard about him.

BROCK: I have heard his name surely.

LEHOVEC: He was one of the greatest really people and that he didn't get the Nobel prize is just – because Schottky had – he had the Schottky defects in crystals, vacancies, yeah, Schottky defects. He had worked on the pentode [00:24:45] in the vacuum tube. He introduced the extra grid there [00:24:50] The Schottky defect, that – and he had developed the theory of the rectifier, space charge layer and the rectifier. So he did all these things and he told me once, "Inventions don't come to the unprepared mind." This is true and when I saw and believed it was Silicone Carbide crystals, I had studies the whole literature and there was a man in Russia named Lossew and this was a time in the early 1930s when everybody looked for crystal detectors and put contacts on crystals for radio. And he had put contacts on silicone carbide and also he sent current through it and he discovered light coming out. So Lossew has this carbide, the light emitting diode in the 1930s, but didn't understand it and he believed it is [________] [00:26:05] like in x-rays when they decelerated the electrodes and sent out light but it didn't make any sense. So I knew about Lossew.

BROCK: From your massive review.

LEHOVEC: From my –

BROCK: Right.

LEHOVEC: Study. And immediately I knew about p/n junctions of rectifiers and all this so I immediately put it together and said, "Well, in these crystals, there must be p/n junctions." And you sent current over the p/n junction and you inject minority carriers and they recombine and this is a light, as simple as that. And I published a paper, number 14, Injected Light Emission of Silicone Carbide Crystals in the Physical Review in 1951 which is a light emitting diode. And I published a second paper on it, number 16, Light Emission Produced by Current Injected in Green Silicone Carbide Crystals.

BROCK: Also in Physical Review.

LEHOVEC: Also Physical Review. And I thought it was a great invention and I wanted to file a patent and went to the Signal Corp patent attorney and he said, “It is nothing. You have simply an ordinary light bulb. You send current through and it heats up and [________] [00:27:33].”

I said, “No, I can do it underwater.”

“No, that is nothing.” And I, at that time, was not – I had nothing to do with patents so I let it go. It was a very important contribution.

BROCK: It also seems it connects back to your original introduction to semiconductors, you know, with your thesis and this photo effect.

LEHOVEC: You're right. I knew all about the injunctions and [________] [00:28:06] and so on. So it was simple really to take the old discovery of the [________] [00:28:14] of Lossew and now with the modern knowledge to [________] [00:28:21] the boundaries of patches in these papers and found their p/n junctions and so on and so on.

But again, somewhat to my dismay, Kroemer got the Nobel Prize for the solid state laser where he took my light emitting diodes, but added a very important thing, hetero junctions. So I mean – so he deserves it, but still I would have thought the discovery of the mechanism deserves something too. Never got anything for it.

BROCK: Was it – was there some time – significant time lag between '51 when you were doing that work and when other people got very involved with light emitting diodes?

LEHOVEC: Well –

BROCK: Or was it more continuous?

LEHOVEC: It was more continuous. I gave a paper at the American Physical Society in December in New York City, I remember, about this light emitting diode and the whole hall was full and they were standing in the corridors listening to my paper and Schottky listened to that and he came to me and congratulated me and said it is very important. But I let it go with that and now – then immediately Bell Lab looked at it and they found some light emission also from Germanium or I think from Germanium, but very weak and then other people took the three five compound and found you [________] [00:30:10] particularly.

BROCK: Which had a better efficiencies than something like silicone carbide?

LEHOVEC: Yeah, it's much more efficient. And so this has became a big field, but as I have in my website, many people acknowledge me with the light emitting diode so it is not that it is overlooked in the literature. And even today, 50 years later, people still cite me in some publications about this light emitting diode.

BROCK: For having determined the mechanism?

LEHOVEC: The mechanism, yes. But unfortunately, very few people, but some do, cite me with respect to the photovoltaic effect. I have to go –

BROCK: Sure.

[END OF AUDIO, FILE LEHOVEC 1.3]

LEHOVEC: The names were Accardo and Jamgocian and I published my light emitting papers with them because they helped with the experimental work and Accardo is right now at MIT and he is a representative of MIT, the foreign contact of MIT with foreign universities and so on. So he is a – you can call him up if you wish to and he can tell you also the history of the light emitting diode and this [________] [00:00:41] And he gave me this – well yeah.

BROCK: Well –

LEHOVEC: Then let me finish my Signal Corps, then we can go to lunch.

BROCK: That would be great. That sounds like a perfect plan.

LEHOVEC: There is really not much to say except now my personal life comes into play with my scientific career. I was 120 percent, 150 percent scientist day and night and people, my colleagues and associates, "Why aren't you married? What's wrong with you? Is something wrong with you? Why aren't you married?" And everybody told me, "You should marry." So I, of course, I have thought about – now I had overcome my chip on my shoulder of being so ugly. I had overcome that already. I had gained self confidence and it really makes a difference in the look of a person. If you feel self confident, you are a completely different look than if you feel with a chip on your shoulder.

BROCK: Right.

LEHOVEC: So, I decided I will get married and I had two platonic friends and this is now another story. So I decided I marry the daughter of a colleague, German scientist, and she had kind of sinus trouble in damp New Jersey. And also one day a man came in spring and it was muddy and rainy in New Jersey and he had a fur coat and the fur cap – and he visited me at the Squier lab and I questioned his attire and he said he had to ski down to the railroad station because I had the snowstorm. And I had become kind of an adventurous over my diversified life in Russia and Germany, the Signal Corps and now a new aspect in life, skiing down to a railroad station in mountainous trees and so on. Sounds fascinating.

And he invited me to come up to see – he worked for a – what I considered obscure company, Sprague Electric, well known for principal capacitor manufacturer, but never heard anything of research from them. And so he invited me for a visit and I came up with my friend, fiancé and we were fascinated by the countryside and we decided I'll leave the Signal Corps and this, of course, from a point of view of career was a horrible mistake because I was a top man in two labs in the Signal Corps. I mean –

BROCK: Did it seem like a –

LEHOVEC: And I just left overnight. I didn't even say goodbye or apologize or explain. I am – it was a horrible – a horrible [________] [00:04:52] mistake I made. Just goodbye and I go. And I came out here and now comes my second career as Sprague and we can discuss that later.

BROCK: Who was the visitor who you met at the Signal Corps?

LEHOVEC: Yeah, he was Dr. Preston Robinson and he was director of – vice president of research and engineering at Sprague and he had made the – discovered the [________] [00:05:29] oxide capacitor.

BROCK: And he was at the Signal Corps in connection with capacitors?

LEHOVEC: He came – no, it's good that you ask that. No. They wanted to go, like so many other companies, into the transistor field. Bell Lab invited all companies to give them a license, but there was a storm going down there for everybody thought, "I want to have going transistors." And they needed somebody, of course, to – so he came to me. He had read my – he was a knowledgeable man. That was a good thing about him. He knew all about Europe universities there. He was a well read man, not like this Dr. Lazzir, [00:06:14] who later came and didn't know whether a transistor is a capacitor six years after that. And they let a man like that go an replace him. But I told you, it was all political. [________] [00:06:27] and get –

BROCK: And defeat Sprague's [________] [00:06:32]

LEHOVEC: And start National Semiconductor. But anyway –

BROCK: Well let me just – I wanted to ask maybe three follow up questions about your Signal Corps experience. One was that private Bell presentation to the Signal Corps on the transistor.

Do you have any memories of that event, you know, who was doing the talking or was it – who was there and –

LEHOVEC: Well there was Schottky there and Bratten and – but it was interesting that in the question period, we questioned and they say it – they talk about a point contact on this so this was the only transistor they had.

BROCK: Right.

LEHOVEC: And they said it will never be a high power, high frequency device they told us. (laughter) Yeah.

BROCK: And we talked for a moment earlier before the recorder was on –

LEHOVEC: Yeah, and may I make a comment there.

BROCK: Oh yeah, sure. Sure.

LEHOVEC: I may have – coming back to the Signal Corps – I right away knew everything for how it works and I may have written a memo for Colonel Young about this and this may have been the memo which was sent to General Macarthur, but I have no recollection of – detailed recollection of it, but I may have written a kind of – when you go to a meeting you have to write something up.

BROCK: A brief.

LEHOVEC: A brief about it and I may have written it for Colonel Young but –

BROCK: And this was the memo that went to Macarthur and then somehow got into the Japanese scientific community.

LEHOVEC: That may have gotten there, yeah, somehow, but I didn't know it was distributed beyond Colonel Young or someone.

BROCK: Well then the last question I had was an interesting patent that I looked at of yours, but I can't remember if it was filed or issued in 1952, but it was on – I think the title was Double Modulator Utilizing Photo-emissive Materials, these rays of sort of – of photo-emissive components and photo detecting components and this whole system. I was wondering if you had any recollections about that patent. You can make a frequency analyzer out of it or could be used for –

LEHOVEC: Of course I wrote –

BROCK: Do you have your patents on that list?

LEHOVEC: Oh here. Where is this paper? Yeah, here it is. Number 15. Soon after I wrote my light emitting diode paper, number 15 I published in 1952. I say a new photoelectric device – devices utilizing carrier injection and in this, I talk about using the – generating a modulated light beam by the injection mechanism and then receiving it by the detector. This is a paper, but I never filed a patent on it because it was published November 1952 so it must have been – and I left the Signal Corps in 1952 so it must have been way before at the Signal Corps and at the Signal Corps I never published a – now, this is a paper yes.

BROCK: Okay, 'cause I do think that there was a patent that did issue for just this sort of work in your name assigned to the Signal Corps.

LEHOVEC: Yeah.

BROCK: On these photo-emissive devices, photo-detecting devices. No matter. Well maybe this would be a good time to break and then we can get into the Sprague story.

LEHOVEC: So what would you like to eat?

[END OF AUDIO, FILE LEHOVEC 1.4]

LEHOVEC: In 1952, in May 1952 I was extremely happy. Everything worked out. I had said at the Signal Corps, "Never make two big decisions at one time." And I had made two big decisions. I had left the Signal Corps and I got married and I came up here and worked wonderful [________] [00:00:30] with the marriage and at Sprague, they gave me a complete free hand. I could hire whom I wanted, I could buy whatever equipment I want and I could do whatever I wanted. So again, it was the [________] [00:00:52] study and I got a group of very good people, diversified group. I got an excellent instrument builder, mechanical engineer. I got a electronic circuit man and I got a vacuum equipment builder and I immediately jumped on silicone. I believed, right away, silicone is [________] [00:01:31]

BROCK: Really?

LEHOVEC: Yeah. And everything was tops and I had the political inroad. I played every week in tennis with R.C. Sprague, the chairman of that at his place. And after awhile, he told me that he has a son, Johnny Sprague, who studies at Stanford and Johnny Sprague doesn't want to come to the company and I should go out there and persuade him to join Sprague Electric. I drove out there, I met Johnny and his wife Jit [00:02:18] and we hit it off very well and he came to Sprague Electric and he was assigned to work under me. So the future owner of the company works under me. I play tennis with the chairman and then I made an incredible mistake. R.C. Sprague really knew nothing about modern electronics and so he felt insecure and so he wanted to have a consultant and he asked me whether I would agree to have Professor Von Hippel [00:03:11] –

BROCK: Von Hippel from MIT?

LEHOVEC: From MIT – as a consultant. I knew Von Hippel. He's a friend of mine. He waned me to work and to come to MIT when I was in the Signal Corps.

BROCK: Hi.

MALE SPEAKER: Are you ready?

LEHOVEC: Yes. I'll take the house –

[END OF AUDIO, FILE LEHOVEC 1.5]

LEHOVEC: Now R.C. Sprague asked me to – what I think of having Von Hippel as a consultant. Von Hippel was my friend and incredibly, I turned him down.

BROCK: Why?

LEHOVEC: Because Von Hippel I had respect as a scientist, but not in my field, not in semiconductors. He had developed the theory of breakdown in insulators, Von Hippel, but I knew much more about semiconductors than he did. So I thought I wanted to save the company money. I didn't need a consultant. Politically, so stupid and what happened is Dr. Lazzir, [00:00:51] this horrible guy, he brought in his consultant.

BROCK: This was the new director of research.

LEHOVEC: Yeah right. Yeah. Yeah.

BROCK: And who did he bring?

LEHOVEC: He brought in Dr. I think Burns [00:01:05] was his name. He was a high level man in Bell Labs in chemistry. Burns [________] [00:01:16] and he was a retired and also he was associated with Stanford and he was a nice guy, kind of a grandfather guy. He came in always shaking hands, "How are you? How are you?" And he became aware – R.C. Sprague became aware that Dr. Lazzir and I don't click too well and so Dr. Burns had a solution. I am a theoretical man and Lazzir is a practical man and he knew nothing about anything. But this was at least an explanation what is the problem between us. Totally wrong.

BROCK: Right.

LEHOVEC: Well, and yeah, what were my contributions? When I came to Sprague, the first transistor was a point contact resistor. You know, they have two pins and they have tiny wires welded to the pins.

BROCK: Right.

LEHOVEC: And then [________] [00:02:33] under a microscope they position the pins very close on the surface of the terminal. I looked at it and I had a very – hired a very nice young man, Armen Fermenian, and he came from Western Electric and he told me he couldn't stand the bureaucracy of Western Electric and that it – right away I say it, "You are my man." And he and I developed the following idea and were not permitted to publish it. So, do you have a pen?

BROCK: Yes. Do you want to draw it in here so I'll have the drawing?

LEHOVEC: Okay, I can draw in here. Yes.

BROCK: I'm sorry.

LEHOVEC: Yeah. We talk. A frame – we took a ceramic frame and on this frame on the low part, we took a Germanium wafer and on the upper part, we took a strip of beryllium copper.

BROCK: I see.

LEHOVEC: And here is – and then we went with a shearing tool to cut this like this. Now we had on the sheet of beryllium copper, we had two point contacts opposing each other.

BROCK: Oh.

LEHOVEC: And then we came with a bending tool and bent the contacts down.

BROCK: Oh, I see.

LEHOVEC: And this was so simple and there was no adjustment of needles and so on and this was extremely stable. It couldn't skid sideways. And it could be made in a little tool by hand.

BROCK: And it would almost be just pressive, you know, could be even automated.

LEHOVEC: Yeah, it was just nothing. And this I showed to Jack Norton and this is modern and this is what he got so excited about.

BROCK: What he saw.

LEHOVEC: They tested it. They were better than the Bell Lab. So simple. And I was not permitted to publish it by Dr. Lazzir. We give secrets away [________] [00:06:01] That was a – but unfortunately, the point contacts of this too became very quickly obsolete and –

BROCK: When did –

FEMALE SPEAKER: ______ [00:06:26] started?

BROCK: You can just put it there. Thank you.

FEMALE SPEAKER: Sorry.

BROCK: Thanks. When did Sprague begin to actually manufacture semiconductor devices?

LEHOVEC: After I left, much later.

BROCK: After?

LEHOVEC: Yes. Because Lazzir prevented it.

BROCK: From going into manufacturing.

LEHOVEC: No. I have to correct myself. I have a thought when they manufactured their devices, they got a Philco transistor license. I will tell you about this [________] [00:07:16]. Well, the next transistor after the point contact transistor was the alloy [00:07:25] junction transistor and the way it was made was again stupid and I immediately improved it tremendously. The way it was made was as follows. They took a Germanium wafer and I put on both sides a carbon tick with a hole.

BROCK: What kind of [________] [00:08:09]?

LEHOVEC: A carbon frame, let's say, with a little hole in it. And they took a little Indium pellet and pushed it, girls pushed it into the hole onto the Germanium on both sides and then they heated it and the Indium melted and fused to the Germanium.

BROCK: Did they use that carbon frame as a susceptor for –

LEHOVEC: Just to hole the Indium dot in place and to orient it. Well, I looked at it and immediately saw there were two things wrong. First of all, pushing a little Indium dot about three or four mills big into a hole doesn't sound right and secondly, Indium immediately oxidized on air. So the Indium has an oxide layer and now they fuse the oxide at the boundary of the P/N junction, which cannot be good. So, [________] [00:09:24] and this is published.

BROCK: Okay.

LEHOVEC: Cut off one end and shape it to have a tiny diameter there. Then I pump from an Indium reservoir, Indium through the u-tube to come out. And when I pump it out by inner pressure on the supply of Indium, a little droplet comes out and rinses off – a little droplet comes out and rinses off. So I break a pure Indium surface and I put the Germanium wafer on top of the capillary and pump the Indium onto the Germanium surface.

BROCK: And then how did you heat it? Oh, so then it would be just a little bead of it on there?

LEHOVEC: No, no. And then I take the Germanium off and there's a little hemispherical dot of Indium there sticking to it.

BROCK: Okay. And then you can just heat it and –

LEHOVEC: I have a clean surface and no problem. So unfortunately, when we had it and with the delays by Lazzir and so on, the alloy junction transistor was obsolete.

BROCK: And this is all happening within the space of just a very few –

LEHOVEC: A few years. Yeah.

BROCK: A few years yeah.

LEHOVEC: The point contact transistor lasted only from ’52 to ’53 and the alloy junction patched to ’54. Well –

BROCK: And this was Germanium you were working with?

LEHOVEC: Yeah. And this – all my publications. Yeah. This alloy junction transistor is published as [________] [00:12:05] with a capillary. That [________] [00:12:09] the reference.

[END OF AUDIO, FILE LEHOVEC 1.6]

LEHOVEC: I just described – it's called capillary alloying and improved alloying method. It was published in the Journal of Electrochemical Society in the year 1961. It was late as that. And this paper number, my paper number is 30. Well, so next comes the grown junction transistor. Again I look at Bell Lab and find what they're doing stupid. Every – Bell Lab – I have no – of course, the story of Bell Lab is that – is the monopoly of the telephone company and the government permits them to have a certain percentage of the expenses as profit. If you do that, the more expenses you have, the bigger your profit.

And with this nonsense, Bell Lab could hire oodles of people all over from universities and it doesn't cost them anything. They make money on them. And then they dismiss many of them and send them to universities as professors and now Bell Lab has the information contacts all over the place and the whole thing is a very inefficient outfit. And when Bell Labs fell victim to their own pride, they believed they are so smart and when it came to a break up of the Bell Lab company, they wanted to keep the computer. They thought, "We are so smart. We will be in computers. Great."

And they flocked totally on computers and they persuaded – well anyway, so. So how did Bell Lab make their junction transistor? They started pulling a crystal with one conductivity type, let's say N-type. Then they put P-type doping into the melt, continued pulling and now with the P-type layer and then re-dope with even more N-type so they make an NPN transistor. So they get one transistor slice, the NP slice, where [00:02:53] a whole crystal pulled. What a way. So here I come with my different method.

BROCK: Is this the surface melting?

LEHOVEC: Yeah right, surface melting. Surface melting with double doping and with consolidation. So per slice I get the NPN transistor –

BROCK: Across the entire.

LEHOVEC: They get it by a whole crystal. Efficiency improvement hundred to one.

BROCK: And Sprague never put that into the production.

LEHOVEC: Lazzir locked everything. He told always, "We put at risk our reputation by unknown new product."

BROCK: Will you pardon me for a moment while I get this –

[END OF AUDIO, FILE LEHOVEC 1.7]

BROCK: This is going whenever you're ready.

LEHOVEC: Yeah, just my Publication No. 23, which came out 1954.

BROCK: And that's from Journal of The Electrochemical Society?

LEHOVEC: Yeah, and I, in my study of the whole field of inorganic nonmetallic materials, I found out that silver iodide has a modification which has extremely high ionic conductivity. And I thought that one could use this to make batteries with a solid material, not liquids like older batteries are—like ________ [00:1:43] electrolyte batteries. And the title of the paper is Semiconductors ________ [00:1:51] Electrolytes in Electrochemical Systems.

BROCK: And this would be opposed to something like a lead acid battery?

LEHOVEC: Right. Of course, of certain limitations, but one advantage is it has infinite lifetime. And I felt a little bit reluctant about it because I realized that this would be the battery used in mines.

BROCK: Like a landmine?

LEHOVEC: Landmines. Because they would last forever, which of course is horrible. So I published with Jay Boulder **[00:02:36]**, who worked with me at the ________ lab at paper semiconductor and solid electrolytes. And I opened it completely ________ electrode batteries, but it never got anywhere because the currents you can dole [00:02:54] are extremely small. So they're only good for keeping a charge on a capacitor forever where there is internal discharge otherwise of the capacitor.

By the way, ________ [00:03:14] who worked under me—and he was an Orthodox Jew, and he had to be—he came from Brooklyn and he had to be home by sundown on Friday night. And so he wanted to leave earlier Friday night and Signacore [00:3:35] would not permit it. And I went to Colonel Young, who is a commanding officer, and got an exception. He could leave Friday night afternoon, early, to make it before sundown.

BROCK: Did Colonel Young have a technical background?

LEHOVEC: I really don't know. I really don't know. We went fishing together on fishing trips, but we didn't talk about science. What a nice man. He had several daughters. I think he wanted me to marry one of his daughters, but I was not interested in them.

BROCK: So, where did you have your laboratory with Sprague? In which building was it? Was it in the manufacturing plant?

LEHOVEC: In an old, old mill—abandoned mill. But it did a pretty good job: awards and so on. It's now the museum.

BROCK: The Museum of Contemporary Art?

LEHOVEC: Yeah, that was my lab there. I continued by working at Sprague and did all the technical developments with only four or five people with me. We poured silicon crystals in high vacuum at Sprague.

BROCK: You _______ [00:05:33] in the vacuum?

LEHOVEC: Yeah, in vacuum.

BROCK: Wow.

LEHOVEC: But when I tried to ________ [00:05:40] contain the liquid silicon, and then came Lazier [00:05:43].

BROCK: Why boronitride?

LEHOVEC: Well, we have to keep the moistened silicon in a container before it crystallized and we couldn't find anything else which liquid silicon doesn't react to.

BROCK: Is boron a dopant for it?

LEHOVEC: Somehow or not, no; one would think so.

BROCK: Yeah. It didn't dry out?

LEHOVEC: And also nitrogen and those.

BROCK: Right.

LEHOVEC: No.

BROCK: That's fascinating. Do you know where that came from? How you came upon that material as a -

LEHOVEC: I don't know. I don't even know if I did or one of my coworkers proposed it. I don't know how it came about. Right away I came to Sprague and I started vacuum equipment to put silicon crystals, and Lazier came, cut down the silicon work. And I was so stupid; I should have left Sprague immediately with my group, got financing from all over the world and start my own company. And I still wrote scientific papers on the sideline.

I did not only erect the technical work and practically generated it, I also wrote scientific papers on strange materials. So I was a very busy man and setting up my own company. Now I have to talk to financial people to arrange space, and it would take me a couple of years out of doing what I liked.

BROCK: Sure. Was there—so, you were there until you went…

LEHOVEC: Oh, I come to this very shortly after.

BROCK: I'm just trying to think. So, when was it that Sprague actually started to manufacture a semiconductor device? Was that in '55 or somewhere in there?

LEHOVEC: Yeah.

BROCK: Okay.

LEHOVEC: One day Ozzy [00:08:21] Sprague came to me and he said, "I want to start manufacturing semi-conducting devices, and I want to become second choice to an established company," and, "Who would you propose of the following two prospects? " Raytheon with alloy junction transistors or Philco with a surface barrier transistor?" Are you familiar with a surface barrier transistor?

BROCK: Right, the very fast ________ [00:09:05]

LEHOVEC: With the jet etched in until there's a very thin layer left, and then they make the contacts on both sides. And my answer was, "None." And he said, "What do you mean?" I said, “Alloy junction transistor’s on the way out. The surface barrier transistor is, in the moment, the fastest transistor, but there are other transistors on the horizon I know about which will be better.”

And I mentioned the mesa transistor. I knew it from scientific meetings and so on. But -

BROCK: That’s the diffused-based transistor?

LEHOVEC: Yeah. But he did the etch around it to have it on a little mesa. And he didn’t listen to me and took the physical [00:10:21] transistor and—here comes the interesting sideline. Well, first off, there’s a professor at MIT—Professor Nottingham.

BROCK: I’ve heard his name.

LEHOVEC: And he was kind of in semiconductors, and he had every year a meeting at MIT by personal invitation only where this handful of semiconductor people got together. And he was an avid skier, and after the meeting he arranged for a trip to Stowe, Vermont to go skiing. And coming up here in this neck of the woods, I became a skier; you have to or you’re miserable.

So, I went skiing. And she had a student who also went skiing—attending the meeting and went skiing—and she had to be my roommate in the cabin up in Stowe, Vermont. And the name of the student was Robert Noyce, and I wanted to hire Robert Noyce but he wanted come to Sprague; he went to Philco. But then he left Philco and went to the Shockley Lab.

So he took the physical [00:12:42] transistor and, to my great surprise, I was proven wrong because Sprague did very well with a physical transistor. Very soon after Sprague became second choice, Philco walked out and Sprague was the only source of the physical transistor. And the physical transistor had been established in a lot of equipment already, and rather than reengineer the equipment with new transistors, they just stayed with the physical transistor.

So Sprague made good money with the physical transistor. They sold the physical transistor of $6.00 apiece. And here came an interesting experience: There was a big government project for national defense called the Minutemen, and Rockwell [00:13:51] International had cognizance of this. And us, as Sprague, took me and said, "We got to Rockwell to sell our physical transistor."

And on the plane, I talked to Ozzy and I told him my philosophy of research. I told him it's to do good work and sooner or later it will be recognized. And his mouth popped open and he said, "But don't you know it all depends whom you know?" This was really his saying.

So we came to Rockwell and he told me, "Don't speak. I do all the talking." So we got in and he pedaled the physical transistor at $6.00 apiece, and he was told that Texas Instrument had been there the day before and they pedaled their transistor for 70 cents apiece. Ozzy said, "I am a medical professional. I can tell you this is impossible." And I felt so ashamed for him because I saw these people look at each other. Because of cost, Texas Instrument made a transistor cheaper _______ transistor [00:15:36]. But, he made good money for a long, long time.

BROCK: Now, where were they making those? Well, I wanted to ask about your involvement in sort of the technology transfer or getting that process going.

LEHOVEC: Very good question. They started a plant in Concord, New Hampshire—a new plant for the field transistor and they hired and bragged about they have invented a new way of hiring top managers. They hire retired people who come cheap. So they retired for the Philco Plant in Concord. The guy named Jesse Ard [00:16:46], who came from Western Electric.

BROCK: A manufacturing guy?

LEHOVEC: Well, I don't know what he did at Western Electric. He knew nothing and was not a very old man, and they needed somebody to run it and they asked me to send one of my persons there and I stupidly sent over one of my best men—this young man who had—design chief, point contact on this Robert Armenian [00:17:27], who hated Western Electric. And he became now the retired top man for Western Electric and he worked for him.

And Armenian [00:17:37] complained to me, "He can't get anything done." When he has a proposal, Jesse said, "I have to think about it," and then he was sitting on it for weeks rather than—and I talked to Jesse and I said, "Jesse, I understand you are not too happy with Robert Armenian. What's wrong?" And he said, "How can you live with somebody who is always right?" So Robert Armenian left very soon and they had nobody really who understands this and it was total disaster, and the yield dropped down to 5 percent and Sprague was frantic.

BROCK: Did Philco engineers come help them get it running?

LEHOVEC: No.

BROCK: No? It was just a license?

LEHOVEC: They gave them all the right recipes. It was not ____________ [00:18:47], but they had no semiconductor expert running it, and they believed they don't need any. So they run it and Ozzy [00:18:56] was frantic and he called me. And there was another guy there whom I didn't know, and he told both of us that we yielded only 5 percent and we're losing money and what can we do?

And this other, incredibly, said, "I am a statistical expert, and what I propose is we randomly twist all the knobs in the production process and by the statistical analysis we find out what should be done."

BROCK: That is a statistician's approach.

LEHOVEC: Nothing about semiconductors.

BROCK: Crazy.

LEHOVEC: And I told him—I said, "Sprague," I said, "First of all, this approach will not work," and he got mad at me. He said, "You shut up. Let me handle him. What do you propose?" And I said, "I take some of my men and I go up to Concord, and you give me one of your production lines and I do some experimental and we will come up with a yield of 35 percent."

And Ernie Ward [00:20:28], Executive Vice President who runs the plant said, "This is crazy, how can you yield," – Ozzy said, "Shut up," and we do both. And I went to Concord and took a couple of people with me, and I me ________________ [00:20:49] guy there; was a nice guy, but he realized right away. And I found out what is wrong with this plant. It was incredible stupid.

Two things go on: I found out on the production line that after ________________ [00:21:18] they had next step where they _____________ distilled water to clean it up. And the individual transistor was on a frame and just switched it in. So ____________ switched it in nowhere the jet washing was not running.

BROCK: The cleaning water was not –

LEHOVEC: Was not running. And the girl took it and nobody would say, "I'm sorry." And then the other one, even more incredible. When it came to testing, they tested the reverse current for leakage and so on, and they had light shining on it so they had photo [00:22:17] currents. And they took good transistors and sold them $6.00 apiece in a way like this.

BROCK: It sounds like just inexperience.

LEHOVEC: I didn't tell the story to Ernie Ward or Ozzy Sprague; I just simply—we chose a girl to ____________ [00:22:40] and made sure there was no light when they tested it and went up to 35 percent yield and I was a hero. Oh, boy.

BROCK: I saw that later on—well, I saw that in January of '59, you filed a patent that used electrochemical jet etching to make these molded [00:23:19] mesa transistors. I was wondering if that Philco process was where you got into jet etching, because I understood—

LEHOVEC: I'm not familiar with _______________ [00:23:39].

BROCK: Oh, it was, I guess, to use—well, next time we meet, or I can send you a copy of that patent and maybe we can talk about that.

LEHOVEC: I've filed many, many patents, and some of them succeed and others, not related necessarily to this. I had been a member of a bowling team, and—are you a bowler? Have you been bowling?

BROCK: I have, sure.

LEHOVEC: And I was able to hit the pocket to get strikes, but I never got strikes; I got splits. And I asked somebody—another bowler—why he took pocket and don't get strikes and he said, "You have nothing on the ball." What does it mean? What do I have to have on the ball? And then I came to the conclusion it must have to do with the spin of the ball.

So, I have to invent something which measures the spin of the ball, and I made an invention just like that. And here is my invention: the ball has a regular set of dots on the surface, and as the ball rolls down the alley, you illuminate it with a laser or light source and the light is reflected. And you have two separate photocell receivers on the reflected light. One is light going through a vertical slit and the other is light going through a horizontal slit. And each slit—light of each slit—generates a period of dots which are due to the pectin [00:25:50] on the dot.

So you can from this decide what is the rotation on an axis like this and what is a rotation on an axis like that, and you can calculate from that the spin on the ball. And I filed a patent on it and got the patent. But again, as I am, I never follow up my patents and much later I realize somebody told me it has been used on a tennis ball—golf balls, even—and so on.

As you correctly say, or expect, I got thrown into the physics of the physical process to help the people there. And this involved two aspects: one was diffusion for the diffused graded transistor, and the other was yellowing [00:27:17], or making the yellow dot, in the field transistor. And yellowing, of course, is determined by the phase diagram, which is solely the liquid phases. So, I am man who hated chemistry and didn't want to study it and ________ [00:27:42] chemistry, eventually.

I got into an analysis of phase diagrams: liquidus line and solidus line. And I discovered an anomaly of the solidus line with respect to arsenic ________ [00:28:13] and I published a paper on thermodynamics of binary semiconductor metal alloys. So here I am with my Paper 35 published in The Journal of Physical Chemistry of Solids in the year 1962 and in which I explained that this anomaly of the solidus line comes from the effect that the electron gas at high arsenic concentrations is degenerate.

And the ordinary chemist worked with statistics which are essentially ________ [00:29:35] statistic and he will be happy to generate electron gas which doesn't obey the ______________ [00:29:45], but the term is ________ degeneracy if formidable in the conduction bend of the semiconductor. And that is the anomaly.

And I had my fun when I went to Europe later to go to chemical places and talk to chemists about their former physicist. And then I discovered another very important effect. We—of course, with diffusion you need to things: one is a surface concentration as a function of the ________ [00:30:01] and the other is the diffusion constant for moving in. And we discovered, experimentally, a way to bend the field transistor that the profile of the ________ [00:30:51] did not check with what was expected.

BROCK: The actual measured profile?

LEHOVEC: Yeah.

BROCK: Okay.

LEHOVEC: So there was an anomaly, and what was wrong? Was the diffusion constant wrong or what was going on? And that, of course, was important for the processing. And I came up with the explanation, namely, again, that high dopant concentration diffuse in a high concentrations. That establishes ________ [00:31:27] and electric ________ dopant gradient, and due to the undiffused gradient of the dopant an electric field is established within the semiconductor and so the dopant does not move strictly by diffusion, but also by drift in the field. And this is drift-enhancing diffusion.

BROCK: Is it this No. 31, perhaps?

LEHOVEC: No, this is also with diffusion, but I think this particular drift—I published it rather late, even though I did it earlier. Here it is, yeah: Diffusion of charged particles into a semiconductor under consideration of a built-in field—No. 34.

BROCK: In solid-state electronics, 1961.

LEHOVEC: Solid-state electronics. 1964. This must be it, yeah.

BROCK: Yeah, 1961.

LEHOVEC: And this is very important because of the whole gradient system change. And so I was thrown into this aspect of production technology.

BROCK: Thinking about your work with the p-n junction isolation—the integrated circuits—I noticed something that looked like it prefigured, in a way, some of that work in your own work, which was – I saw a patent that you filed in June 1955 called Multiple Junction Transistor Unit. And this was a device that had, I think using a rate-grown method, had an NPN structure that I think the patent describes—if I read it correctly—as being rate-grown.

And then on that last N region, there are two alloyed P regions.

LEHOVEC: Yeah, yeah, but this is a p-n junction isolation patent which I filed.

BROCK: But this is four years earlier.

LEHOVEC: Well, it took a long time to issue the patent. This is a patent –

BROCK: You know what? Let me see if I have it here in my folder.

LEHOVEC: You mean I give to you?

BROCK: No, no, I printed out some patents.

LEHOVEC: No, no, I show it to you. I have it here, too. Where is this book now? What did I do with the book?

BROCK: Is that that other one? This one?

LEHOVEC: Did I give it to you?

BROCK: You did give it to me.

LEHOVEC: Oh, I see; good. Yeah, this is my only copy so –

BROCK: There's an even earlier patent. See, this is one that you filed in April 1959. There's an earlier patent that you filed in 1955 that is for, essentially, a structure that looks just like this part: like an NPN within two alloyed P regions.

LEHOVEC: It may be a combination of two transistors in one unit.

BROCK: Yeah, that's exactly right.

LEHOVEC: Right, but I filed several patents of this sort, but it does not give the isolation from each other by p-n junction.

BROCK: It doesn't. What interested me was when I was looking at the drawing here –

LEHOVEC: It looks similar like it.

BROCK: It does.

LEHOVEC: But no, I don't recall it anymore. The problem with filing my p-n junction isolation patent: of course, in the patent, it's important to get a very general claim, but all you have to do is give one example for producing this sort of thing. And the example does not have to be practical at all. And for this reason, many people held it against me with my p-n junction patent invention that I claimed something which is utterly impractical to do the way I showed the structure.

BROCK: The wire interconnections?

LEHOVEC: No, the whole structure. I mean on opposite sides. But I only wanted to demonstrate p-n junctions for isolation, and for that it was perfectly fine. But then there comes the people who say, "Oh, this isn't practical." It doesn't have to be practical. As a matter of fact, you don't want to get sometimes the best method to achieve ________ [00:38:58]. Why is it you can first develop it?

But I know if I said, "Well, patents," ________ [00:39:11] we have 30 patents on ________ [00:39:14] and I never took a second look at them.

BROCK: It was interesting because it is essentially these –

LEHOVEC: How to make the many junctions. This is for the general electric method: by changing the rate going to make the junctions.

BROCK: Right, and it was a combination of rate growing and then your capillary sort of alloying technique to make sort of a—it almost looked to me—it's in a way like one of those p-n p-n four-layer diodes, you know, where you serve two overlapping devices, if you will. In any case, would you like to talk about the p-n junction work now here or should we wait and tackle that back at your house?

LEHOVEC: Well, the p-n junction isolation is, in great detail, described in the paper I gave you. And, of course, I wish you would return it after you're finished, but you can make a copy of it if you want. And I would like to have you advise not only about the content and how it is written, but also to whom to send it for publication. Is there a journal where you send historical papers like this?

BROCK: There sure are.

LEHOVEC: If you can advise me about a journal where to send it, I would appreciate it.

BROCK: I will.

LEHOVEC: Because both Noyce—but okay, now I can give you, very briefly, what happened. I went to a meeting of the I Triple E at Princeton, New Jersey. And there was a RCA scientist from Sweden; I don't remember his name. And he gave a visionary paper of thousands of transistors hooked up in big airwaves: essentially computers, but he foresaw this big airwaves for doing certain circuit manipulations.

And I looked at it and I thought that hooking thousand transistors together—soldering them together by interconnection not practical. We have to do it on one chip.

BROCK: This was an RCA person?

LEHOVEC: That was a man working for RCA, and he was from Sweden. I don't remember his name. And so driving back in my Corvette with red leather seats, I went north from Princeton. I got the idea using p-n junctions for the isolating elements of the components on a single chip.

BROCK: When was this, ’59?

LEHOVEC: I think it was ’59, but it was an I Triple E meeting at Princeton, New Jersey. And you could perhaps track it down, I would appreciate it because I am not quite sure right now; I think it was ’59.

BROCK: Was it a summer meeting?

LEHOVEC: Well, it was definitely not in the winter because I had my roof down.

BROCK: So it could have been Solid State Circuit Conference?

LEHOVEC: It could be.

BROCK: I’ll look into it. But the paper was on these large discreet –

LEHOVEC: If you find Princeton, New Jersey, and I would guess it was in the fall or summer, not in the spring. And I came to Sprague and we had a local man here—Vince Sweeney [00:44:15] —but he's called Hill [00:44:17] for some reason. Nice guy; a local man at Sprague. And I told him, "Hill, I have a very important invention. We must file it immediately." I knew immediately that this is the whole future of electronics.

And though we have many important inventions, we give it a docket number and I say, "Not good enough. We have to file it immediately. If you don't file it, I'll file it." "You're not permitted to do so." I said, "My contract says the patent belongs to the company, but it doesn't say I cannot file it." I wrote up the plans, I made the drawings and I sent it to the patent office in Washington.

BROCK: Did you work with a patent attorney privately?

LEHOVEC: No, I did it all alone, but by then I was quite experienced with having some patents with Sprague. And then, I left in voluntary exile in Europe. This is another story.

BROCK: After filing the patent?

LEHOVEC: After filing the patent. And I stayed in Europe almost two years, and the history of it is the following: Why I went to Europe. This is Dr. Revere Lazier made life just impossible for me. He pulled the tricks like that. I usually come very early in the morning. One day I didn't come. I got a message from my secretary, "Ozzy Sprague wanted a conference with you."

Then a couple of weeks later, the same thing happened. "Always wants a conference when I'm not there; something's going on." So I parked not in my assigned spot. I was, at that time, had become ________ of Lazier ________ was a bad guy [00:46:38]. I had become Director of Research. And I parked in the general parking place and a telephone call came, "Conference with Ozzy."

So I walked in and there's Dr. Lazier sitting there, "You are here?" So this type of trick he played, and I had enough of this. So I went to him –

BROCK: To?

LEHOVEC: Dr. Lazier. And I said, Bill, I would like to ask you for a favor. Of course he knew how we stood. "What do you want?" I said, "Bill, you know I'm a research man, after all, and right now with all this administration, I cannot do my research. I want to go back to research." "Oh, smart guy. Smart guy. Go back to research."

"But, I cannot do it here because all these people come in. I need quietness; I need separation. I need to go away." "Oh, good, good, good, go away." "I need to go far away." "Wherever you want to go." "I want to take my family with me." "Of course you take your family with you."

"I want to take an assistant with me." "Why do you need an assistant?" "Well, for research I need one assistant." "Okay, you'll get an assistant." "And his family?" "Yes."

And then I looked him in the eye and I said, "And I want to keep my salary as Director of Research." "Are you crazy? You go to Timbuktu and you want your salary as Director of Research?" "These are my conditions. Goodbye." I turned around and left and I got it. I kept my salary as Director of Research. I could go anyplace in the world where I want with my family and an assistant.

BROCK: Why do you think they agreed to that?

LEHOVEC: This I wondered. Why would they agree to that? Because both sides of the fence saw advantage in it. Lazier saw the advantage to get me out of the picture. He considered me a threat that he should be fired and I should take his position, which would have been the right thing, of course. And, Johnny Sprague worked under me and he obviously would be, eventually, the boss.

So there was a problem to take him from under me and put him above me, so I figured I make it easy for them. I get out of the way. Then, Johnny Sprague is no stupid. He sees what's going on with Lazier. Lazier will be out, Johnny Sprague will have learned his position.

I come back from Europe and work now for Johnny Sprague, my friend. In Europe, I become a top skier. I take the Austrian Ski School. And I figured it all out, and that is why both Johnny Sprague and Ozzy Sprague gave it to me to get me out of the way for Johnny Sprague to get up, and Lazier gave it to me to get me out of it. So everybody was in agreement.

BROCK: Now, was this at the same time that this intrigue was going on that you told me about before with the other senior Sprague brother: the Julian Sprague and that? [00:50:31]

LEHOVEC: No.

BROCK: Okay.

LEHOVEC: This was going on much earlier.

BROCK: Your going to Europe was earlier?

LEHOVEC: Much before.

BROCK: Okay.

LEHOVEC: I went to Europe about ’61, I think it was, and this went on ’54 or maybe ’55: the whole setup with Julian Sprague.

BROCK: That was earlier, then, in the mid-50s?

LEHOVEC: Yeah.

BROCK: With the National Semiconductor and all that.

LEHOVEC: Yeah.

BROCK: Okay.

LEHOVEC: And actually, the man who started National Semiconductor may ________ Dr. Osleen [00:51:15] and –

BROCK: He's a Raytheon person or something?

LEHOVEC: No, Dr. Osleen came from the Secret Core. [00:51:23] He was actually a ________ [00:51:27] and when the craziness came and everybody went into transistors, ________ [00:51:34] sent him up as their transistor man. And he soon got out of it and he separated and started his little company.

And I was told that one day somebody comes in his office and told him, "I acquired the majority of shares of your company. I give you one day to get out." And this was Julian Sprague who had financed his son, Peter Sprague.

BROCK: Of taking over.

LEHOVEC: Of taking over this little company. And the company was important to them because, first, they got some of my people and secondly, they got—Osleen was a very popular guy, and they got all the licenses from other companies. And National Semiconductor never developed anything new.

BROCK: They just second-sourced?

LEHOVEC: Yeah, second-source and so on. And a billion-dollar company doing very well, but they never contributed anything at all.

BROCK: In this period or at all?

LEHOVEC: At all. I don't know anything what National Semiconductor contributed to the electrical field.

BROCK: I'm not sure I know the answer to that.

LEHOVEC: They were good businessmen, obviously.

BROCK: I wanted to ask you, also, about: you described hearing this paper about these large transistor arrays and then thinking the way to do it would not be large arrays of discreet components, but integrated on a single block of material—this monolithic idea. Could you tell me a little bit about your experience of the discussions at the end of the 50s about microminiaturization and these ideas of functional blocks of material that sort of prefigure integrated circuits?

LEHOVEC: Well, there is a little bit described in the paper which you have about a British guy who gave, I think as early as '51 or so, but it's described in my paper. I talk about things that all the important electronic components can be made from semiconductors, so let's do it on one chip.

BROCK: Were you aware of that? That's Denard, or whatever his name is?

LEHOVEC: No, I forgot the name, but I mentioned him in my paper. But he didn't, of course, say how to do it because what really is—and this is what irks me. If you want to pinpoint one aspect which makes this integrated circuit possible, it is the isolation of the components from each other; nothing else is as important as this aspect because without the isolation from each other, couldn't component conducting semiconductor [00:55:18]. So forget plane of circuitry and forget all the other aspects, and contact lines or insulating layers. These are details.

Well, anyway, so I came back and I went to Europe and came back and my first question was, "What happened to my patent application?" And I was told, "You got the patent." And I am now a little bit confused. For a long time, I was under the belief that they simply granted me the patent without any office action, nothing. But now, looking at this patent—my patent—belatedly, I find out things which I don't fully understand.

One thing is that the figures in the issued patent are signed by Connolly and Hutz.

BROCK: Yes, I see that.

LEHOVEC: Which is a patent attorney of Sprague.

BROCK: Right.

LEHOVEC: But they had nothing to do with my filing. I filed without them on my own. And the other thing is, there is one trigger with a lot of locks like this and I don't understand what it is. It doesn't mean anything to me.

BROCK: It's supposed to be a different configuration or something?

LEHOVEC: I don't know, but I hate it when I looked at it. This is not what I had in it. But anyway, so I got the patent and I said, "This is fine." And then, Sprague relation to Connolly and Hutz is the following: Connolly and Hutz is a patent licensing firm in Delaware, and Mr. Connolly is a director of Sprague Electric.

BROCK: And a patent attorney?

LEHOVEC: One of the owners of this company, Connolly and Hutz, is a director of Sprague. And, Connolly is a good friend of Lazier. Lazier was at Pfizer [00:57:48] in Delaware and Connolly and Lazier were engaged in land development together. So Connolly was the guy who brought Lazier in. Well, anyway, so far from Connolly.

BROCK: So they may have had some role in the development of your patent application while you were out of the country?

LEHOVEC: I really don't know how it came from the moment I filed, and unfortunately, I don't have a copy of what I filed, and the real patent that is issued. But anyway, then they sent from time to time one of their people—Connolly and Hutz—to Sprague to just talk about walking through, shaking hands, "How are you?" and so on. And he came to my office and he said, "Oh, one of your patents has been challenged as an interference, but don't worry, we'll take care of it."

I said, "Which one?" and he said p-n junction. I said, "Oh, my God." And I asked Vince Sweeney [00:59:09], the local guy—my friend—for a file on it and he gave me the file. And in the file was a letter by Ozzy Sprague to Connolly and Hutz. And in the letter, Ozzy Sprague says, "Do not defend the patent, but get from Texas Instruments whatever you can."

BROCK: In terms of –

LEHOVEC: I don't know. So I was upset. I said, "They will not get away with that." The patent belongs to them, but it is my mental property, and if they don't defend it, I defend it."

BROCK: Because it's –

LEHOVEC: My creation. Just give it away for nothing? So I make a big fuss. And stupidly, I didn't copy the letter by Ozzy Sprague, and when I got the file back the letter had disappeared from the file, and they decided to defend it.

So my next step was to call Connolly and Hutz and say, "I would like to participate in the defense of my patent. Who is going down?" "Mr. Hutz is going down." I never had met Mr. Hutz, so I said, "Mr. Hutz, may I ask you what is your background?" No background in semiconductors and he's going down to defend this patent.

BROCK: He's a patent attorney?

LEHOVEC: Yeah, he's a patent attorney. I said, "Mr. Hutz, do you mind if I go with you?" He said, "No, no, come with me." So I went with Mr. Hutz to Texas Instruments to a hearing by the federal court, and Mr. Hutz turned out to be a very nice guy, but totally ignorant.

And we got to Texas Instruments in Dallas and a big hall was set up, and we had a little table and Mr. Hutz and I—and there was a long table facing us and patent attorneys—several of them—a professor from Bonner [01:01:36], Illinois, whom I knew—Professor Mauer[01:01:42]—as their consultant, and Mr. Kilby, supposing the inventor of this isolation, and court stenographer. And in the rear, a whole production line was set up—a whole production line.

And I said, "Oh, my God." I knew that Kilby worked on integration. I said, "My God." It turned out they had nothing. And they had three suggestions: they had it all why I shouldn't get the patent.

Mostly, two of them are obviously stupid. The first suggestion was that in a junction transistor, you have the junction from the emitter to the base and the junction from the base to the collector so you have two junctions which isolate emitter from collector. So you have the p-n junction isolation and a junction transistor. So I said, "Well, everybody knows a junction transistor is not there for isolation from the middle to collector, but current has to flow in order to make the transistor working. So this is not isolation; this is p-n junction conduction."

BROCK: Right, like the opposite.

LEHOVEC: Then they said since most of my conductor devices, if not all, involved p-n junctions, if you put enough semiconductor devices on one chip, you automatically come up with p-n junction isolation because you have so many p-n junctions. So there is some way of p-n junction isolation.

Now, I am not listed in the final result at the patent office as a participant because it was too late for me to be announced. So I could not even speak, but I could tell Mr. Hutz what to say, and he just repeated exactly my words. So I quickly drew a circuit and Mr. Mauer from ________ [01:04:25] said, "If you have enough devices, you are automatically."

So I quickly drew up a circuit with three capacitors and three diode resistors and one diode and had him like a fish on the line. He said, "The circuit with several semiconductor components." He asked, "What kind of components: diodes, capacitors, resistors? How many components?" "Oh, seven components." "So, is this a multi-component circuit?" "Yes, yes."

And after I had him, I quickly sketched a actually make it [01:05:08] of the circuit with cuts in the way for isolation and had him again on the line. "If it's the same circuit, where are the capacitors, where are the diodes, where is this?" "Yes, yes, yes." "Is there a p-n junction isolation?" "No." So that was the argument that ultimately come up, but nothing in the production line.

And the head made a pickup from a record [01:05:46] where something was up and down and ________. And their pickup was a sheet of silicon, and at the end of the sheet of silicon was a needle which tracked along the roof [01:06:04] and the silicon sheet was clamped on the side so it would bend up and down, up and down. And they had a resistor on the other side—it was the PT type silicon [01:06:15] and had an ________ layer as the resistor on the upper side and ________ as a resistor on the lower side.

Now if it goes up, the lower side is stressed—is expanded—and the upper side is compressed. And the other way, it goes down. And that affects the resistance of the layers. So they got a response to up and down, and it was a ________ pickup.

But, they say in the explanation how they made it: they took this P-type semiconductor slice and they undiffused N-type around the slice, and then they ground off the N-type here so they had two resistors. And these two resistors are separated from each other by the to p-n junctions and into the P from the N.

BROCK: And that was supposed to show that they already had it?

LEHOVEC: They had already made used p-n junction isolation to separate two resistors from each other. But, I listened to that and they had said they left off the end of the silicon before they soldered the ________ [01:07:52] to it. I asked for clarification. I said, "Why did you leave the N-type off if you connected any way with the ________ electrically? It is an unnecessary process."

"We didn't leave it off," he blurted out. Oh, boy. "So you haven't got two separate transistors; you've got one resistor with a contact in the middle of that." I caught him on a lie. And they had said they left it off here to have two separate transistors.

BROCK: So they didn't have the sandwich, just had the continuous intake there? Wow.

LEHOVEC: Imagine Mr. Hutz, who understood nothing about electronics, defending me at this point. So we came back and then there was a brief hearing for the higher patent court in Washington, and it was essentially a formality, and –

BROCK: Did Kilby file after you or before you?

LEHOVEC: There is a guy named Succina [01:09:24].

BROCK: Yeah.

LEHOVEC: You've heard about him?

BROCK: Yeah, I saw that article by him.

LEHOVEC: Right. He wrote recently an article, and if you could tell me later—or write me—where this article is published, because Succina worked at Sprague, too.

BROCK: Oh, did he?

LEHOVEC: Yeah, so I know him very well. And he looked, in this article—which incidentally, he sent me a draft of it and asked me for my comments and I gave many comments about it, but he didn't follow up on the comments. He's a good friend of me and I know his family and so on, and I'm very disappointed that he did not take my comments into account.

But he wrote this paper, essentially, in the dispute between Noyce and Kilby. It was not—kind of a sideline—and I'm disappointed that I appear only very occasionally in the paper. And he starts—on the first page, he acknowledged inventors of the integrated circuits, Kilby and

Noyce: he starts on the first page. While Professor Gundy[01:10:59], as I explain in my paper, he wrote the first book on computers.

In the preface he says, “The whole field is based on two papers: by Hernie [01:11:14] and by me.”

BROCK: Hernie [01:11:14] is Planar patent?

LEHOVEC: Nothing with Kilby and nothing with Noyce. Well anyway –

BROCK: But then did Sprague, once you defended the patent and you had that –

LEHOVEC: When we got the patents, I told Ozzy Sprague, “Get out of this transistor field, hire an accountant and a lawyer and collect royalties from the whole field. He could have become a billionaire.”

BROCK: Sure.

LEHOVEC: No, I'm a manufacturer. And he used the patent for trading it for stupid little other patents, and then he wrote me a letter that said, "Signed by Ozzy Sprague, Chairman of the Board of Directors: A new invention has turned out to be a valuable asset of the company." The Board of Directors expresses their gratefulness to me. No Christmas bonus, nothing.

But what particularly pissed me off: when I came back from Europe, it was as I expected that Lazier was gone, Johnny Sprague had just positioned and they had split up and hired two new people: one nice guy, but his big count was a surface tension of soaps [01:12:59] and the other one was a Bell Lab [01:13:02] guy. The Bell Lab guy's name was Link Folger [01:13:06] and the other guy came from Stanford, and his name was Dr. Folks [01:13:12], the surface tension guy. And they had split up my group and given me to these two people, and I was there now, essentially –

BROCK: Without a group.

LEHOVEC: Without a group. And, of course, I was considered the senior man or whatever, but if I wanted I got my salary, but I had no group.

BROCK: And were they still just churning out the Philco transistors at this point?

LEHOVEC: No, the Philco transistor was gone then, and then Johnny Sprague started his – actually, Sprague had another big asset. Their two newcomers to Sprague developed or had developed the implant technology, and when a little group separated from Texas Instruments—they separated from Texas Instruments and formed their own group—and they came to Sprague and saw the implant and said, “Ah-ha, that is what we need for the transistor?”

And they formed their own company, and this company—very soon, Sprague bought into this company. I forgot what the name –

BROCK: Mustek.

LEHOVEC: Mustek, yeah. Was very soon looming, and then they collapsed. They went into memory or something and collapsed.

BROCK: Got caught up in that.

LEHOVEC: Yeah, but they had really ________ [01:15:08] implant and the p-n junction isolation. Sprague had everything.

BROCK: That was Ken Manchester, right?

LEHOVEC: Manchester was one of the guys. And he ran, eventually, one of the transistor plants in Brewster [01:15:23].

BROCK: And they were making silicon transistors there?

LEHOVEC: Well, when I came back from Europe and I saw that they had hired these two people and left me, essentially, out in the cold, I was very mad at Sprague, obviously. And the only reason I stayed with Sprague was to defend my p-n junction isolation because I knew that this would be my place in history. But at the same time—and this was somewhat—might almost say immoral—I made the decision I would not contribute anything of value to Sprague Electric but take salary from them.

Of course I would contribute, but I would not contribute with any thing of commercial value to them. So what did I do? I thought, "What can I do for them?" Well, the crystal structure of titanium oxide [01:17:15], which is their main item, was not known, surprisingly. The position of the atoms in the –

BROCK: Sure.

LEHOVEC: So I published a paper on the crystal structure of titanium oxide. So here I am, again, in a completely new field and this paper is actually held up today, very much, I'm surprised. Oh, Paper No. 44 in The Journal of Less Common Methods, published 1964, The ________ Structure of Betatantium Oxide [01:18:10]. So here I am, again, in a completely different subject, and it is quoted today every year.

BROCK: As the structure?

LEHOVEC: But it was stupid because I had ideas of ________ [01:18:36] and I deliberately didn't pursue them because it would have given Sprague something. I had, for instance, the idea of the charge property device [01:18:48] and I didn't want to work on it.

BROCK: Because then it would belong to Sprague?

LEHOVEC: And then finally, after the fight with the p-n junction patent was won, I said, “Now it’s time to leave Sprague.”

BROCK: Which was 1966 or so?

LEHOVEC: Yeah, something like that. And I went to Sprague and I said, “I would like to work in other fields in addition to working for you,” and I got commissioned to become a consultant to Sprague and remain now as a consultant to Sprague and I consult other people. And I consulted McDonald Douglas on ________ [01:19:47] transistors in California, Los Angeles ________ from Sprague.

[END OF AUDIO, FILE LEHOVEC 1.8]

BROCK: Okay, the recording is going again.

LEHOVEC: I attended a meeting of The Electrochemical Society in Houston, Texas because of Johnny Sprague, and it must have been in the late '50s. And at this meeting was a scientist ________ BELD [00:01:03] and he presented a paper which was completely misplaced for the type of audience—Electrochemical Society—on the surface states at silicon oxide relating to capacity ________ [00:01:29]. And it was a highly mathematical paper and it was indigestible, certainly, to chemists.

And even to me it was difficult to follow, so I told Johnny Sprague, I said, "Don't bother following to take notes. I know the general idea and I can work it out straightforward." Well, when I looked at it at home, it was not straightforward.

And I derived of how to determine the concentration of surface states such as silicon/silicon oxide interface from capacitants ________ frequency and so on [00:02:32] and I presented it at the Stanford Research Conference at Stanford before I left for Europe. And I had taken some measurements at Sprague. I took Johnny Sprague as a co-author and –

BROCK: Was that with the use of the so-called CV dots [00:03:16] to do those capacitant voltage measurements? [00:03:18]

LEHOVEC: Yeah, it's my Publication No. 33 and it was the I Triple E published in the I Triple E Transactions Electron Devises, Volume 8 in 1961: Lehovec, Slobotskoy and Sprague [00:04:43], and it was presented at the Stanford Solid State Device Research Conference.

BROCK: That's the Effective Surface States on Silicon/Silicon Dioxide Capacitors. So those are those CV dots?

LEHOVEC: Right.

BROCK: Okay.

LEHOVEC: And I described how to derive the concentration of surface states from CV measurements [00:05:12].

BROCK: Wow.

LEHOVEC: And there was in the audience probably 12 men from ________ [00:05:23] well-known man. He is not a professor at Stanford.

BROCK: Gibbons? No.

LEHOVEC: And he had a student named Thurman [00:05:30]. And then, I sent his paper to the physical review and left Europe, and then I got—I asked from Europe's Johnny Sprague, "What happened to our publication?" And he said, "Oh, it was rejected," and he didn't even tell me. I said, "Why?" and he gave me the comments of the reviewer, which was total nonsense.

He said, "Rather than rushing into publications, the author should first find out how to control the surface state." Well, the whole field worked on it for years—thousands of scientists—and I saw the hand of either the Professor of Thurman or possibly Bratton [00:06:26], who hates me. Bratton hates me because Bratton is an experimental tinkerer and I am an idea man and I write papers and present talks with great ideas and he describes tinkering with experiments. So Bratton doesn't like me.

BROCK: Personally or was there a personal difference?

LEHOVEC: No, no, nothing personal. He objects me that I just spill out great ideas without doing a lot of work and I get credit for them and he has to do all this tedious work.

BROCK: Speaking of experimental work, did you—going back to that p-n junction isolation patent—did you fabricate a device like the one pictured?

LEHOVEC: No.

BROCK: What sort of experiments did you do in connection with that? Any?

LEHOVEC: I didn't need to experiment. I knew p-n junctions just for the purpose of isolation; that's all.

BROCK: Okay.

LEHOVEC: And, of course, if I wouldn't have gone to Europe ________ [00:08:00] higher speed. And then, the ________ stupid, but I took exactly the same paper and published it in

Europe—my Publication No. 17—in the Physical ________ Solidity, Volume 3 in 1963. [00:08:45] Lehovec, Slobodsky and Johnny Sprague—and they accepted it and printed it immediately. But in the meanwhile, Thurman, who was present at my lecture, went to, I think, IBM and he published the paper.

But the field in Europe then—I elaborated on this subject and this is my Paper No. 42 published in Solid State Electronics, published 1964—and coming back from Europe, a friend of mine is Mr. Dunlop [00:09:44], who came from GE and published—is the editor of Solid State Electronics—a good friend of mine—and I told him, "I worked this out in detail, but it's a very long paper and I hate publishing long papers and reading long papers."

So he persuaded me to publish it anyway in his journal, and it is 20 pages long—59 to 79—and it gives a total analysis of this equivalency of it, which has become known in literature as a Lehovec, Slobodskoy Equivalency of the Surface Space. So this is one of my most acknowledged contributions.

BROCK: Because that technique of interrogating the surface states using CV measurements was everywhere.

LEHOVEC: This was everywhere. Every wafer I produced _______ [00:10:53] capacitor to do it to find out what the surfaces are and adjust to the implant accordingly. So, again, it's –

BROCK: Ubiquitous.

LEHOVEC: Yeah.

BROCK: Fascinating.

[END OF INTERVIEW]