



## **Oral History of Zhores I. Alferov**

Interviewed by:  
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**Zhores I. Alferov, May 16, 2012**

**Rosemary Remacle:** I'm Rosemary Remacle from the Computer History Museum. I'm here with Doctor Alferov to talk about the early years of semiconductors and the Soviet Union, Soviet State. And particularly because your personal history has been so well-covered in your presentation to the Nobel audience, explaining the work of heterostructures, I would like to have you talk about some of your personal accomplishments, and then let's talk about the larger Soviet semiconductor universe: some of the technologies, some of the people, some of the milestones, that kind of things. So, can you give me a brief introduction of who you are, who your parents were? I read your autobiography which is really beautifully charming, I loved it, but for the record can you tell where you were born and where you went to school? That kind of background.

**Zhores I. Alferov:** So, I was born on 15<sup>th</sup> of March in 1930. My parents were born and grew up in Byelorussia, in the western part of Russia. My father was from a poor family When he was a young boy, the teacher in a small—it's called in Byelorussian "mestechko," it's a small town—Chashniki, the teacher noticed him and gave him a chance to study at the, what to call it, city school. It approximately corresponds with the eight-year school in the Soviet times. And he graduated seven years of this eight-year school, so for his background he was a sufficiently educated person. But he was poor. His father during the summer time stayed on the Zapadnaya Dvina river cutting forest—there's a forest, Platy, don't know how to say it, a forest across the river from Byelorussia to Latvia, and in winter he worked as a shoe-maker. There were four children, three sons and one daughter, and his eldest brother came to Saint Petersburg in 1910 and started to work at the *Siemens Schuckert* company, and the next year my father

left Chashniki in Belorussia and came to Saint Petersburg and also started to work at the factory. So it has frequently happened in the pre-Revolutionary Russia that the poor people from agricultural areas went to Moscow, to Saint Petersburg, to a big city just to get a job. And from Byelorussia many people came to St. Petersburg. I remember, when I became the chairman of the Leningrad Scientific Centre of the Russian Academy of Sciences, at one of the presidiums of the Academy I asked some specialist in demography to deliver the talk about the pre-Revolutionary St. Petersburg, and he told that in 1914 the population of St Petersburg was 1.8 million people and Byelorussians were second after Russians in population, 200 000, only because many poor Byelorussians left Byelorussia for St Petersburg to get the job. When the WWI started, my father went to the army and he fought against Germany in cavalry, and he was fighting and he was a good soldier, a cavalryman, but he became a member of Russian party of Bolsheviks before revolution.

**Remacle:** So, he was an early believer?

**Alferov:** Right you are, and he came to St Petersburg on the exactly the next day after the October revolution has happened. He participated in the meeting in Smolny. Then he participated in Civil war. And he was promoted from a non-commissioned officer—it was the first level from a private—he became the cavalry regiment commander. The Civil war finished, then he was in the border guard, he came to a very small town, mestechko, Kraysk, you see, because he was just appointed as a responsible for a big part of the border with Poland. And he looked for a good house to stay. So, he decided that one house was good enough, and it was the house where my mother lived. It was another poor family. My grandfather from the mother's side had six daughters. He wanted a son, but after six daughters he stopped. They also were very poor; they lived in a house with the earthen floor. He was a horse-driver. And the Polish count, a rich guy, once invited him and told him, "You serve me very well, and I'd like to express you my gratitude for that. Go to my garden and choose three Carelian birches." Carelian birch has a very good wood from which good furniture is made. So, he cut these three birches, made some planks and sold them and bought a house, a horse, a cow -it became the best house in the village.

**Remacle:** He was very clever.

**Alferov:** And my father chose this house. But there were also some problems after about six or seven months. They fell in love, my father and my mother. But my father was Byelorussian, from an Orthodox family, and my mother was from a poor Jewish family. And her mother, my grandmother, liked my father, but they were strongly against from the religious point of view. So, it was practically impossible for them to marry. And what did my father do? He went to his commander and asked to have him moved to the 100 miles south on the same position. And, in November of 1922 (they told me many times about that) when it was raining hard my grandfather on the mother's side helped to steal his daughter from his house, while the grandmother and the other sisters were sleeping. But they just took some little luggage and the grandfather helped to steal his daughter to another place. They came to a different place, they married, they lived together and then they visited the house of father's parents. They too were strongly against this

marriage, also from religious point of view. They were Orthodox believers and they didn't like at all that their son has married a Jewish girl. They forgave him later, but my grandmother has never forgiven my mother. She has never answered her letters. When the first son was born, in a short time, my elder brother, as my father was a strong believer in the victory of Communism and so on, he named his first son "Marx" in honor of Karl Marx. And when they visited the parents of my mother, the grandfather was happy, but the grandmother, no. So it happened. And I think that by my birth I have been born in an international family.

**Remacle:** You started international.

**Alferov:** Yes. And when I was born, in 1930, when we lived near Vitebsk—I was born in Vitebsk, it's a big city in Byelorussia—they were waiting for a daughter, but a son was born, and just a few days before my father has read a big article about Jean Jaures, a famous French socialist, the founder of the newspaper / *'Humanite*, and the founder of the French socialist party, so he decided that if a son was born he would give me the name "Zhores." Then in a very short time my father was sent to the Northern part of our country, near Archangelsk, and he became a director—he left the army by then and he became a specialist in the forest industry, and then he became a student of what we call an "industrial academy." The students of the industrial academies were usually not very young people who had some experience, but a relatively low level of education, and they were getting the education there. So my father graduated from the Archangelsk Industrial Academy. He studied there from 1932 and graduated in 1935, and he got the diploma of the engineer-manager—it's a special type of diploma—of the cellulose paper industry. He became a specialist in the cellulose paper industry and an engineer; he graduated with the excellent marks.

My mother also had some good education, because when she was growing up in this small village, just like my father, the local teacher noticed her, and it was not very simple to admit a poor Jewish girl to a special kind of school, which was called "ministry school," which corresponds approximately to a seven-year education. But she got there, she became an educated person, with all excellent marks, except for one, for she didn't study one subject at all and there wasn't any kind of mark, "Orthodox religion." It was excluded from her curriculum.

So, for that time she was also an educated person, and when my father was studying at the industrial academy in Archangelsk, my mother was also studying at what we call "rabfac," "worker faculty." My mother was also a very educated person; she read a lot and so on. So, my father got an engineering education, and became an engineer in the cellulose paper industry, and we traveled a lot through the country, because before the war people were frequently sent—members of the party and engineers were sent to different places to organize new production and so on. So, after he graduated from the Archangelsk Industrial Academy, he was appointed as a director of a big enterprise in Stalingrad, and then he became a chief of a big trust of the forest industry in Siberia. It was a hard time. Usually when we

came to a new place, we didn't have an apartment at the beginning. Then the father was appointed on the new position. It was a very good time when we lived in Stalingrad, two years on the Volga river.

**Remacle:** Did your mother share the Bolshevik ideals that your father did?

**Alferov:** My father and my mother both shared the Bolshevik ideals, but my mother was not a member of the party. She was going to become member of the party in 1924, but then during the session she refused to do so, as she strongly disagreed with the head of the district committee who became an enemy of my father. We stayed in Stalingrad—maybe I should tell a few words about that—in 1937, and all the people in our country know what it means, the year 1937. It's a special year. This year is the 75<sup>th</sup> anniversary. It was the time of the strongest terror. Many people were arrested in 1937. It's a special word in our history, 1937. My father was a director of a big enterprise in Stalingrad, and this enterprise belonged to the Ministry of Railways, the Minister was the People's Commissar, as they said then, Kaganovich. And once father came—he told me about that many years later—once he came to Moscow in 1937 in summer, and one of the friends of him who had a high position in the Ministry, told him: "Ivan Karpovich (that was my father's name, my grandfather was Karp, my father was Ivan)—Ivan Karpovich," he told him, "You can't return to Stalingrad. You will be arrested immediately. In order to save you I'll go right now to the People's Commissar Kaganovich and propose to send you as a chief of a big trust of the forest industry (which belonged to the same ministry) in Novosibirsk. Do not return to Stalingrad. Go to Novosibirsk. Send some letter to the family without any explanations." The communication system was weak at the time. The connections between the different cities were weak. They had a plan to arrest many people in Stalingrad, but if you escaped you were safe. So, my father was sent to Novosibirsk, he wrote to my mother a letter, and there was little luggage—by train we arrived in Novosibirsk. Many years later, in 1955, my father met his chief engineer from that enterprise, who was arrested and spent seventeen years in jail. So, my father was saved this way. We arrived in Novosibirsk in summer of 1937...

**Remacle:** Let me ask a question. What would be the offence that that man would have committed that would have put him for seventeen years in jail? What did he do to get put in jail?

**Alferov:** Nothing. The majority of the people—why we call it the great terror majority of the people that were arrested in 1937 were arrested because of some denunciation that some petty enemy has written. Mostly it happened this way. And it was directed especially against the old members of the party or the people who held some position. So, we arrived in Novosibirsk. My father was appointed to a big position. At the beginning we lived in a hotel, as the apartment did not exist yet. And the 1<sup>st</sup> of September came. I was seven years old then—that time children went to school at the age of eight years, so I would have had to go to school the next year. And my mother decided that as we lived in the hotel, and my brother was going to school (he was six years older than me), I should go to school too. I didn't like the idea. I didn't want to go to school at all. But together with my brother—in fact, one of the biggest influences on my life was exerted by my brother. I was always with him. He taught me. I started to play chess when I was five years old. He taught me that. I started to read when I was five—also my brother taught me that.

So, I went to school, and it was a very interesting school. Now this building houses the theater of puppets. But then it was a seven-years school. My brother was in the seventh grade, and there was a teacher in that school who was an outstanding personality. She played a very important role, I think, in my whole life. Her name was Maria Mikhailovna Sosunova. She graduated from the Bestuzhev Courses in Saint Petersburg and before the Revolution she had decided to go educate people in Siberia. And she became a teacher. She specialized in teaching only the children of the first year. Usually teachers taught the first four years, but she only specialized in the first year. She was not married, she lived in the school. She had an apartment there, and she took the new children and spent with U.S. the whole day.

**Remacle:** Why did you say you think she affected you throughout your life?

**Alferov:** You see, two months later we got an apartment and my mother decided that I stop going to school. She came to take me from school, and the teacher said, "No, Zhores likes to study. He has a personality. He should stay at school." And I decided to stay too—I didn't want to go to school at first, but after two months it became very interesting. In fact, we went to school, then we went home and then we returned to the school. She played with us; she gave each the special tasks. And as I already could read and write she gave me different tasks, and she started to give me some tasks on arithmetic, on some natural studies—she just woke up my interest to study. Many years later, in 1944—we lived in Ural region during the wartime—I read in a newspaper that Maria Mikhailovna was awarded the Lenin Order—the highest order in our country—for her work as a teacher.

**Remacle:** Wow, that's an absolutely entrancing story.

**Alferov:** In 1939 he decided to start working in the paper industry, and he was appointed as a director of the biggest cellulose factory in the Leningrad region, "Syaz'stroy." It's about 100 km from Leningrad. We lived there for 2 years, and then, just before the war, there were built five new cellulose factories, named by the numbers—"Number One," "Number Two," "Number Three," "Number Four," "Number Five." The initiator of this was Georgy Mikhailovich Orlov, who worked in the Paper Institute in Leningrad. He wrote a letter to Stalin with this proposition. He wrote that the war was coming, and we needed powder. Usually it's produced from cotton, but we need cotton for clothes, and there was a technology of producing powder from the wood, and in order to develop this technology he proposed to build new factories. In two years five special factories were built, and before the war my father was appointed as a director of one on these factories in the Ural region. He came to pick U.S. up on June 22, 1941. We liked living near to Leningrad, but he was sent to Ural. And it was a lucky chance again. We left and went to the East, and all the war we spent in Ural region. He became a director of this factory, the factory was working very well, so he got some decorations and so on. But my brother graduated from school on June 21, 1941. The next day the war started. He wanted to become an energy engineer and applied to the Ural Industrial Institute, as he thought the energy was the most important problem. He was seventeen, and people were enrolled in the army at eighteen, one year older. But he decided that studying during the war is not the right thing and that it was necessary to go to the front. So he became a volunteer in

**Remacle:** So he moved up very rapidly for a young man.

**Alferov:** Yes, and those were the special troops where all the soldiers were from the Pacific Navy or from the border guard. The officers of the company, battalion and so on were the officers who participated in the war. There were three "Staling brigades" specially trained to fight in Stalingrad. In October 1942 he arrived in Stalingrad and he fought just next to our house, he knew that place very well. So he fought from October and to the end of the battle, as platoon and later as a company commander. He was wounded lightly, so he kept fighting, and he got a medal for bravery. When the Stalingrad battle was over, they made from the two "Stalin brigades" a one guard division, the 94<sup>th</sup> guard division. Later it became the Berlin guard division. Many years later, by the special decision of the council of veterans I was made an honorary member of this division and got a special medal from them. He also participated in one of the biggest battles during the war, the Kursk battle. There he was heavily wounded to the head and he was delivered to Barnaul in the Altai region, where we lived for a year before the war. He was very heavily wounded, so that he lost hearing a little bit, but he still wanted to fight against the fascists. We met him when he was going back to the front from the hospital. He was going by train from Barnaul, stopped in Sverdlovsk, and we with my father went to Sverdlovsk. My mother has gotten a small vacation earlier and spent a week with him in Barnaul. And we spent 3 days together in Sverdlovsk. I remember these three days practically by the hour, all the stories he told U.S.—I can tell you plenty of the stories. And he wanted to return to the same regiment, but it was not possible. In German army there was a rule: every wounded soldier or officer, when he returns to the front, is sent to the same troop where he was fighting before. It was a very clever decision, because when you return to the same place, people know you, you return just like to your family. But in our case it was a "we know better where to send you" policy, so he was sent to another division, and later I came to know that the troop where he fought before and the new one were positioned in about 5 km from each other. An in 1944, on February 15, he was killed in action. He played a very important role in my life.

**Remacle:** Did he impact—did his decision... ah, wonderful.

**Alferov:** <shows a photo> Here he's 16 years old.

**Remacle:** I can see you are related. You have the same eyes.

**Alferov:** Yeah.

**Remacle:** Did his decision to be an engineer influence you in your choice?

**Alferov:** Yes, I think so. You see, during the wartime I decided to become a pilot. My brother wrote me in a letter, "After the war we won't need pilots, we'll need engineers, so you'd better study physics, mathematics and go to an engineering school." So he wrote me in 1943.

**Remacle:** So, where did you go to school? Where did you get your advanced degrees?

**Alferov:** And after the war—I'll just tell you a very short story, okay? I found the grave, where he was buried in 1956. In 1968 I was together with Dima Tretyakov, my co-worker, at the big semiconductor materials factory in Svetlovodsk near Kremenchuk, in Ukraine, transferring our LED technology, gallium-aluminum-arsenide technology, LEDs, infrared LEDs to this factory. And then, on Saturday, June 21<sup>st</sup>, we went to the movies, and the movie was about the war. We were going to leave Svetlovodsk for Kiev next day, and then fly to Leningrad. From Svetlovodsk to Kiev we were going to go by a "Raketa" ship, a small fast ship. And there was only one stop in Cherkassy, and Cherkassy were not very far from Hil 'ki, where my brother was buried. So I told Dima that we should maybe stop and visit the grave. So we stopped, and I took a taxi, because there was no bus, and by taxi we went 111 km (I remember that). We came to this small village on the hill with a big grave—3000 people were buried there. So we with Dima stayed by this grave, when an old woman came to us, asking, "What are you doing by our grave? Some relatives there?" And Dima told her my brother has been buried there. "His brother was fighting for our village?" Thirty minutes later the whole village came to the grave, about 150 people. They brought the tables, they brought the moonshine and food, and we sat there for six hours in my brother's memory. So it just shows the people.

**Remacle:** Wow, that's an amazing story.

**Alferov:** And just after the war, in 1945, my father was appointed the head of cellulose industry of Byelorussia, and we came to Minsk. Minsk was in ruins. I remember, when we arrived at the railway station, we took the car and drove to the suburban area, where a small apartment has been rented for us. There were only ruins. Only in suburban area there were some small wooden houses left. And in Minsk, the capital of Byelorussia, there was only—at the time it was separate, girls' and boys' schools—one boys' school for the whole capital city.

**Remacle:** What was the population of Minsk at that time?

**Alferov:** It's difficult to say, maybe a few tens of thousands.

**Remacle:** OK, I understand now.

**Alferov:** And we had in our school some outstanding teachers. They were great, and especially great were two teachers, those of physics and of literature. The literature teacher was also a chief of our class, Raisa Grigorievna Barom. She was a Jew and lived in Minsk before the war; she had the title "the honored teacher of Byelorussia." The teacher of physics, Yakov Borisovich Meltserzon, taught in a special way. He delivered lectures to us. He just came to the class and spoke for two hours. And in the end of the term he gave U.S. a special kind of a test, with 12 different questions on the pieces of paper,



and there were 22 children in the class, so only two people could have the same question, and he gave them to the ones sitting in the different parts of the classroom. So, we wrote the answer and solved the problems, and afterwards he put the marks for the term. It was very interesting, but once, at the end of the third term—I answered everything and everything was right, but in the task the answer, which I gave, was 3.632262, like that. And he wrote, "That's right, but in this case it's better to write  $3.63 \times 10^6$ ." And gave a 3 to me [C]. The mark was not very good. I studied well, but I got a 3, instead of 5 or 4 [A or B]. I told my mother about that, and she went to school and told him that her son was a very good student and so on. Next lesson he came, started the lecture, and then told me to go to the blackboard and started asking me. He said, "Someone in your class is not satisfied with his mark. I must check his knowledge." He was asking me for 45 minutes, and then said, "OK, we go on the next day." Next day he asked me again. He asked me all the physics for the ninth grade and then started asking the questions for the previous grade, where I made some small mistake. He said, "OK, you do know physics," and gave me 4+. But after that I was always getting only 5 from him. He asked me some small question, I answered, "Right, five," and so it went. And it was the last grade, when he delivered a lesson to U.S. where he told U.S. how the oscilloscope works and explained the radar system. I was so excited that I decided to become an electronic engineer. And he advised me the best place, Leningrad Electrotechnical Institute. So ...

**Remacle:** So, for you it ended like that. So, after the Electrotechnical Institute can you describe the next steps in your career?

**Alferov:** The Electrotechnical Institute, you see... we have old and interesting traditions of education in our country. Leningrad Electrotechnical Institute, which had also born a name "Ulyanov-Lenin Electrotechnical Institute" since 1918, just after the Revolution, was founded in 1886 as an engineering college for the telegraph engineers. In 1898 it was transformed into the institute. In 1905 the first elected director, not an appointed one, appeared, and that was Alexandr Stepanovich Popov, the Russian inventor of radio. And after the Revolution it played a very important role in the electrification plan, and also in radio electronics. Maybe it even became the number one school in this area. For example, Moscow Energy Institute specialized in some energy problems. But Leningrad Electrotechnical Institute—we called it "weak current institute." The best radio engineers graduated from our institute. An outstanding radio engineer, Aksel Ivanovich Berg, worked there. The first electrovacuum tubes specialty was opened and the Electrotechnical Institute by Prof. Shaposhnikov. So, in radiotechics and radioelectronics, vacuum tubes electronics, of course, it was the place of education number one in the whole country, it had a very good tradition.

**Remacle:** What year did you enter?

**Alferov:** The Electrotechnical Institute? In 1947. And in 1950 or even in 1949 I delivered the talk about Stoletov's work at the students' scientific conference. Stoletov was a Russian scientist who discovered a few photoelectric phenomena. And I was excited by them and delivered this talk. And one of the

associated professors of our institute, Natalia Nikolaevna Sozina, invited me to work with her. She noticed my talk at the conference and asked me to work with her in the laboratory. And it happened rather frequently, at that time, at least, that the students were working at the labs in the Electrotechnical Institute, and not just worked, they got salary as an addition to the stipend. So, she invited me when I was in the third year, and I started to work in the free time in the lab. For the first year I worked without getting paid, just out of interest, and the next year she told me, "Zhores, you're doing a good job working with me at the laboratory. You spend a lot of time here. Why not get a salary?" And so I started getting a half salary of an engineer. I was a rich guy. She carried out the research in the area of semiconductor films and photoconductivity in semiconductor films, so I started to do this job. And that time, as my specialty was vacuum electronics, vacuum tubes, but I worked with semiconductor films at the lab, so I had to start to read on semiconductors.

**Remacle:** Is this the first introduction to semiconductors? You haven't heard about it in your education?

**Alferov:** Yes, you see, at that time I was getting education in vacuum tubes. Jack Kilby was educated in vacuum tubes at the University of Illinois, we have the same specialty.

**Remacle:** Which semiconductor materials were you working with?

**Alferov:** I was working with semiconductor films for photoconductivity, plumbum, sulfur, and with tellurite.

**Alferov:** My teacher, Natalia Nikolaevna Sozina, wanted me to work at the Electrotechnical Institute when I graduated. But I came to know that there were three vacancies for us, those who has graduated that year, at the loffe Institute. And I told Natalia Nikolaevna, "I like you, you're a good teacher, but loffe Institute is the right place for me. Please, help me to get there."

**Remacle:** Why did you want to go there so much?

**Alferov:** You see, I read on semiconductor physics, and then I read an outstanding book, "The concepts of contemporary physics" by loffe, and it became a textbook for me. loffe was a very charismatic scientist, look at him. <Points at the portrait>

**Remacle:** Yeah, his eyes are very powerful.

**Alferov:** He was the founder of the Soviet physics. He was the founder of the first physics research institute. He was a student of Roentgen. He got his PhD with Roentgen's guiding. Roentgen wanted to keep him in Munich. But loffe decided to return to Russia in 1906. Due to his Jewish origins he could not

get to the University, he only could get a position in the Polytechnic Institute, because it was organized by Sergey Yulievich Vitte and belonged to the Ministry of Finance. And it was not that strict about the Jewish people. In the beginning of 20th century he understood well that the quantum physics is the new physics and would determine the development of physics in general. And he understood another thing, that the new physics is the basis for the new technology.

**Remacle:** How many people in Russia—Soviet Union—maybe, still Russia at that time understood what he was talking about?

**Alferov:** When?

**Remacle:** In the 1920's.

**Alferov:** Oh, you see, not so many. Together with Mikhail Isaevich Nemyonov they founded in 1918 the first Roentgen Radiological Institute with two departments, one, the medical radiological department, headed by Nemyonov, and the physicotchnical department headed by Ioffe. And they were to be directors of the institute one after another. The first director was Ioffe, the second was Nemyonov. After the three years of existence of this institute it was divided into three new institutions, as they understood that it was not possible to be directors one after another. So, Ioffe founded our institute. The next year, in 1919, he founded the physicommechanical department of the Polytechnic Institute, and it was the first faculty or department in our country, where they combined the education, very strong, in physics and mathematics with the engineering subjects. It was the first department to educate the engineer-physicists, and many scientists came from this department.

**Remacle:** So, how difficult was it for you to be accepted there?

**Alferov:** You see, at that time Ioffe Institute was not very big, but it belonged to the Academy of Sciences and also to the First Department, to the PGU (Pervoe Glavnoe Upravlenie), later it became "Sredmash." Ioffe was the person who proposed in 1942 to start the nuclear weapon program in our country. He proposed Kurchatov as the head of this program. And many of his students—Artsimovich, Aleksandrov, Kurchatov, and many others, Landau, Kikoin, Khariton, Zeldovich began to work at the Kurchatov Institute. Ioffe was in the beginning a one of the leaders of our nuclear weapon program. I told a joke at the recent annual meeting of our Academy of Sciences in my speech, as people like to talk of innovations today, "Look, there were 2 absolutely successful innovation projects: one—the Manhattan Project in the US, the second—Soviet Atomic Project. The people who worked for these projects were very important for success. For the U.S. the people problem was solved by Adolph Hitler, because all the leading positions were occupied by the outstanding scientists who emigrated from Europe to the US..."

**Remacle:** It is true!

**Alferov:** "...for our atomic project the problem was solved by Academician Ioffe. His students solved these problems. He brought them up, and they became scientists under his guidance." But when I happily got to the Ioffe Institute, I was appointed there, you see, I wrote to my parents, "Dear father and mother, I've been appointed to the Ioffe Institute and I will be working under Ioffe's guidance," but when I came to the Institute, Ioffe was not there. He was not there, because—I did not know that—when he was 70, two years before, Beria decided to take him out.

**Remacle:** Why?

**Alferov:** You see, I think he considered Ioffe dangerous—he called him a "German spy," as he was a student of Roentgen's and a member of the German Academy of Sciences before he came here. Ioffe was dismissed from his position, the new director didn't have very good relations with him, and a couple of months before I came to work there Ioffe has left the Institute and organized a semiconductor laboratory under the Presidium of the Academy of Sciences. So, when I came there, the Institute was small, majority of the outstanding scientists has left for Moscow, Ural, Sarov or Arzamas-16, as they were occupied with atomic problems.

Ioffe started the semiconductor physics in our country. The classical systematic semiconductor research started at the Ioffe Institute in the beginning of the [19]30s, 1930–1931. In my Nobel lecture I've pointed out two very important papers, one—Zhuze and Boris Kurchatov, brother of Igor Kurchatov, where intrinsic and impurity conductivity of the semiconductors were experimentally discovered for copper oxide, and another by Ioffe and Frenkel, the first article about the tunneling phenomenon. So, I'm absolutely sure that the transistor could have been discovered in the Ioffe Institute. But the majority of the scientists has left semiconductor physics for the atomic problems, nuclear weapons being the most important one.

**Remacle:** Would you say that the development of the nuclear weapons and the weaponry in general was the driver for the development of semiconductor devices, the transistors and the integrated circuits?

**Alferov:** No, no.

**Remacle:** What would you say was the driver then in the Soviet Union?

**Alferov:** In the Soviet Union the driver for the development of transistor and semiconductor devices were John Bardeen, Bill Shockley, Walter Brattain, American physicists.

**Remacle:** So, the competition?

**Alferov:** The special kind of competition. You see, what I'm saying, if, for instance, we've kept the people at the Ioffe Institute and they would not have been sent to the atomic project, for example, Davydov, a brilliant theoretician, started to work in the nuclear program, maybe it would have all been discovered here, as we've performed the systematic semiconductor research from the beginning of the 1930s. If you take a look at the Nobel lectures, you'll see that the Nobel lecture is a very interesting source of knowledge. If you look at the John Bardeen's Nobel lecture, its title is, "Investigations that led to the discovery of point transistor," and he pointed out three very important points, the first—Wilson theory, the second—Frenkel photoconductivity theory, the third—rectification theory by Mott, Davydov and Shotky. So, he mentioned Frenkel and Davydov as the source of discovery of transistors. But in the U.S. the driving force for the discovery of the transistors was—the precursor was the development of radar system during the wartime, as we needed again point contact detectors. Vacuum tubes are no good for high frequency detection. So, development of silicon and germanium for the detectors was carried out during the wartime and in the first years after the war. Crystalline detectors book—there was a book—it was our desk companion at the time. And the task of the Bell telephone was to create a switching device, an electronic switching device instead of electromechanical switching. But Melvin Kelly, the executive vice president of the Bell Telephone, was an absolutely outstanding personality. When he invited John Bardeen, Bill Shockley, Gerry Pearson who also was an outstanding personality, I knew him well, he was a professor in Stanford. And Kelly told them, "OK, we need electronic switching, but also it would be very important if you do some research and we would be able to confirm quantum, mechanics of the condensate matter. In my opinion, when the executive vice president invited scientists and gave them such a task, everything would be all right in this company.

**Remacle:** I think you're right. So, when did you meet Bardeen and Brattain and Shockley, when did you become aware of them and their work?

**Alferov:** You see, I came to work to the sector of Tuchkevich laboratory, and we had a special task: to create a Soviet transistor. I came to work, and there was a special decision by the government.

**Remacle:** Which body of the government?

**Alferov:** Just Politbureau, very high level. You see, after the discovery of the transistor it became absolutely clear for specialists that we came to a new type. I think Axel Ivanovich Berg who was responsible for the development for the radiolocation radar system in our country, played a very important role at the time. And he was the director of the biggest research institute that belonged to the Ministry of Defense. So, at first it was point contact, but the PN junction transistors appeared. And it became absolutely clear that the PN junction transistors are the solution. So, four institutions in our country by a special decision of our government were put in competition—who would be doing better and first. Lebedev institute in Moscow, laboratory of Bentsion Moiseevich Wul, Physicotechnical Institute in Leningrad, laboratory of Prof. Nasledov, subsection of associated professor Tuchkevich, laboratory of Prof. Kalashnikov, Institute N-108, which belonged to the Ministry of Defense, and its director was Axel

Ivanovich Berg, and the laboratory of Aleksandr Viktorovich Krasilov, Institute No. 160 at Fryazino near Moscow. These four laboratories competed to create the first PN junction transistor. I came to the lab when we started this work. And Academician Tuchkevich (later he became academician) said—it was a small group of young people who have just graduated from different institutions; there were two people who were a bit older and who've graduated just before the war and during the war served in the army, Subashiev and Uvarov, and then Alec Lebedev from the Leningrad University, the son of Academician Lebedev, Nikolai Yakovchuk, a radio engineer for LETI, and me. So, Uvarov developed measurement of transistor parameters. Yakovchuk developed radio circuits with transistors. Me—transistor technology. Lebedev—growth of germanium crystals. So, we started the work. The first PN junction transistor was made in our lab on the 5<sup>th</sup> of March in 1953.

We understood that it was very important, that we had to compete, and it was clear that this was the birth of new electronics. And it was also the birth of new physics. And one of the textbooks for U.S. was Shockley, *Electrons and Holes in Semiconductors*. It was translated in Russian with the title *Electronic Semiconductors*. It was the main textbook for us. I still have a copy. So, there were November Proceedings of IRE (Institute of Radio Engineers) in November 1952. We called this journal our Bible. Because how to make a PN junction? By growth—it's too complicated a technology. And then in this magazine appeared an article on alloyed germanium transistors, indium alloy transistors. So we decided that this was the solution. I developed this technology, and there were plenty of problems. One of the very important problems which has been solved by me and which gave U.S. a big advantage—you see, there's a PN junction, but you also need an ohmic contact to the base. Ohmic contacts were made even in our lab before me, but I thought of putting copper from solution on the germanium surface, and solved it, but it rectified frequently due to the big resistance. And I understood well that the N<sup>+</sup> contact must be the best. And stannum foil which existed in the lab has 2% antimonite in the stannum foil sheet. So I just made a kind of small rings out of it, put them on the germanium plate, (*draws a scheme*) here was the indium and here—these stannum foil pieces, alloyed, and it became a N<sup>+</sup> contact with a very small resistance.

**Remacle:** How much time did it take you to kind of think through this?

**Alferov:** It took me about a month. I noticed that the technician, Liza Abramova, always made these contacts so that they had big resistance. No amplification by the voltage. So we had problems with the multiplication in this case by voltage due to big resistance. How to make it smaller? N<sup>+</sup> contact. It was just described somewhere, I forgot where exactly. But the idea to make stannum foils and to alloy that, that was my idea.

**Remacle:** So, when did you actually meet John Bardeen personally and have a conversation with him?

**Alferov:** At the semiconductor physics conference I looked at him.

**Remacle:** This was in 1960?

**Alferov:** Yes. And in my banquet speech at the Nobel ceremony I quoted his speech at the Prague conference.

**Remacle:** And, please, talk about the integrated circuits, both in the U.S. and in Soviet Union, the growth from transistors to integrated circuits.

**Alferov:** You see, it's important, I should like to emphasize the following thing: the importance of transistors and especially the PN junction transistors was estimated in our country immediately. And, for instance, the technology of alloyed transistors was transferred to Svetlana company in 1955. In 1955 Svetlana started production. So, the laboratories in the scientific institutes and the new electronic industry—there were a lot of changes, for some time it was the Ministry of Radioelectronics, then it became specially "of Electronics" and so on—we have always interacted. Then, it's also interesting in my opinion—estimation of the chips in our country came also in a very short time. So, the discovery was made by Jack Kilby, and the by Noyce, the most important contribution. But the importance was just estimated immediately. And Viktor can tell you even more about that the decision of the central Party Committee on the creation of Zelenograd, 1961, and it was created specially for this goal.

**Remacle:** For the manufacture production?

**Alferov:** No, not the manufacture production, for development. "Angstrom" and "Micron" were just some kind of first development, but then it was created "Semiconductor electronics" in Voronezh, "Integral" in Minsk. So the importance was seen immediately.

**Remacle:** OK, let's go ahead and talk about where the centers of semiconductors were established, and establishment of Zelenograd and how you all worked together.

**Alferov:** You see, I still think a lot about all that problems and I still consider—I can't blame myself, because I was 30 years old at that time I've only defended my candidate thesis in 1961, I started my heterostructure work in the end of 1962, I changed my topic, so I couldn't have played a very important role in the government and so on. But in my opinion, the background of our semiconductor physics, the physics research in general, the level of education, especially in electronics, you see, vacuum tubes electronics have been born in our country on Svetlana. It's practically impossible to say how important was the Vekshinsky group in 1920s. Then plenty of new kinds of vacuum tubes, like "mayachkovaya 1 amp a," there were plenty of them, look, for instance, in many areas, many chamber magnetron was created in NII N-9 on the Kurchatov street, not far from here. It was an electrophysical institute in the beginning that was founded by Academic Chemyshev. You see, the background for electronics in the Soviet Union was great. And then, for instance, Ioffe, Kurchatov, Vavilov, Aleksandrov understood, mostly due to the

weapon problems, the importance of nuclear weapons. But if there were a scientist who was close with the government and who would have explained in the beginning how important the semiconductor electronics is, that could have changed the world, and not only technology, but the life too. And the background in science, in physics, in technology exists in our country. Yes, in the 1950s and at the beginning of the 1960s we just copied what the Americans did. Nothing more. We can speak of Davydov paper in 1939, and, for instance, Shockley put in his PIN junction theory the first reference to Davydov, though in the next paper he omitted that and only put the reference to himself. Yes, Frenkel, an outstanding theoretician, who created the knowledge for the semiconductor physics. Then we had a very good young generation. And there were only two countries in the world that could really compete in this area, the U.S. and the Soviet Union. And if someone would have explained to the political leaders that microelectronics, the chips, and after that the first lasers and optoelectronics are very important not only for the weaponry, the missiles, but they could also change the life of the people, we could have had absolutely different results. Even on the level of development of the country in general. But, you see, we've just competed in the military sphere.

**Remacle:** It seems to me, and you may correct me as I may be wrong here, that the one of the big differences is the fact that while there certainly was the military point of view in the U.S. and a lot of the early semiconductor and microelectronics' applications were military, space...

**Alferov:** Yes, the chips came later, and at first it was the Minuteman and Apollo projects!

**Remacle:** Yes, Minuteman was the first big contract that TI got for their jobs.

**Alferov:** And Jack understood that very well. I've discussed that with him.

**Remacle:** I've never met Jack Kilby, but I've talked to Charles Phipps, who was his office maintain and he was there when the IC was first discovered, but my point was going to be, that in parallel with military, and rocket, and space program there were people like Bob Noyce, John Hume, who were trying to figure out how to make money, I mean, "money" money, not just sell some kind to the military kind of thing. And that parallel activity didn't exist in the Soviet Union. Can you talk a little about that?

**Alferov:** Yes, yes, you see, there's a big difference between the psychology of the Soviet people at that time and the American people. The first person to notice and describe that better than anybody else was our great poet Mayakovsky. He in his big article "My Discovery of America" in 1924 just wrote about this main difference: the Americans always keep the money in mind, they never say "you look well," they say "you look for a million dollars," they never say "you look bad," they say you look for five cents."

**Remacle:** That's very interesting and very true.



**Alferov:** And at the beginning of the 1960s was a special time in our country. You see, with Stalin dead—if he had lived a few years more, maybe the new terror would have started. So he died in the right time. Then the country became much freer. We've started to feel much freer. Then we've started to live a little bit better. In the 1950s we only lived in the communal apartments, and only in the 1960s what we call now "Khrushchev houses" began to be built, and after the war—Stalin did many clever things too, because the biggest salary for scientists in our country was in 1946, established by Stalin, and after that it only became lower. The salary of the scientists were very good. You got your candidate degree, next day you became a senior scientist and got 3000 rubles as a salary, the same as a director of a big factory. Then, after the war a new generation of the educated engineers and scientists appeared. And there were lots of young people who wanted to show what they can and also to compete with the Americans. It was just the inner feeling—to compete with Americans.

**Remacle:** Pride?

**Alferov:** Yeah, "we must do better and we must do first." During the 1950s we've just copied Americans, but in the 60s the new generation of Russian scientists started to invent new things. I'm absolutely sure for instance that Leonid Keldysh's theory of tunneling phenomenon definitely deserved the Nobel Prize. He must have gotten it with Leo Isaki. Then there appeared new and very interesting developments in the semiconductor physics, in different areas—exiton, it was born in our country. Theoretically and experimentally there were lots of very good works. Then, excuse me, I've started the heterostructures, and here we did practically everything first. Sometimes one month earlier. Sometimes two months earlier. But every important step in heterostructures, the experimental ones, theoretical consideration, Kroemer, yes. He deserved his Nobel, but all the experimental results, the new experimental phenomena, new devices, the first double heterostructural lasers, the first solar cells, the first transistors, many other devices—we did first. They repeated later, sometimes they did not know—I remember how I delivered my talk at Bell Telephone in 1969. I remember how people at Bell Telephone were impressed by that. They have developed only single heterostructural lasers, and I told them about the double. But then, of course, money were also important, even in Soviet times. And I proposed later, in the 70s, to create something like the start-up companies. I proposed that together with Evgeny Velekhov and Academician Inozemtsev Nikolai Nikolaevich supported us. But the Ministry of Finance said no.

**Remacle:** Why do you think the Ministry of Finance cancelled that? They didn't understand, didn't have imagination?

**Alferov:** They are bureaucrats.

**Remacle:** They are the same the world over.

**Alferov:** No, no, there were some advantages in our country nevertheless. I can tell you. You know the British writer Charles Snow? He's spent some time in the Kavendish laboratory, he was a friend of Sholokhov and of Kapitsa. He wrote an excellent book, *Variety of Men*. And he once wrote his article that the Russians are very clever. Why? He said, because the leadership in Russia belongs to the engineers, not lawyers. Unfortunately, in 1985 we lost this leadership, and lawyer Gorbachyov became our leader. And now we have a lawyer again.

**Remacle:** And we have a lawyer!

**Alferov:** But we used to have engineers!

**Remacle:** That's an interesting concept, I didn't think about that at all.

**Alferov:** I thought about that a lot.

**Remacle:** I bet you did! So, I would still like to know, when you have started to have the ability to travel outside of Russia, the Soviet Union, and to meet your peers, your colleagues around the world—were you surprised at how far ahead or how much you had accomplished without the collaboration? With just what you knew inside the Soviet Union and the Eastern Block Nations?

**Alferov:** No, you see, the 60s were the gold time for semiconductor physics. We published our papers—sometimes, of course... for instance, my first author's certificate, the patent for the double heterostructural laser was secret in the beginning. Because they saw "laser" and put "secret." So, the priorities were about 4 months before Kroemer did, but it was published much later, because there was no permission for publishing. Instead of that I published some articles and made some special kind of references that "it was proposed by and so on." But in general the 60s were the gold time. We were open, many foreign physicists visited us, we started to travel abroad, and, you see, before the war we had plenty of foreign scientists the Ioffe institute, and for Ioffe and others the international cooperation had always been very important. Then the times of the nuclear weapons came. But then in 1956 Kurchatov initiated the talk about the thermonuclear reactions. In the U.S. it was secret. And he delivered a public talk in the UK. And the 60s were the gold time for us. We started to travel and to have meetings. First of all, you see, as in the absolute majority of cases in semiconductor electronics—sometimes Russians did publish articles, but practically all the most important things were done in the US.

**Remacle:** Inside companies many times.

**Alferov:** And we copied that. And then in the 60s we started to compete, we started to propose new things ourselves. And for us, for example, the first meeting was in 1960 in Prague, and I met Jack Pankov

that time and had a discussion with him, my first impression was, "OK, he's not so clever, I'm not so stupid!" And of course I would like to say that the American physicists, our competitors, John Bardeen, Nick Holonyak, and many others, they evaluated U.S. very highly. And practically from the beginning when we established personal relations, it was very good relations.

**Remacle:** Person-to-person, independent of the government.

**Alferov:** Yes, right, the government created a lot of problems for us.

**Remacle:** Both governments did!

**Alferov:** But we overcame these problems. But of course, there were a lot of problems. For instance, my first international award, and I'm very proud of that, it was the Ballantine medal of the Franklin Institute. It was my first award in general. The Lenin Prize came later, I won the first recognition from the Franklin Institute. And who have got the Franklin Institute medals before me from our country? Pyotr Kapitsa in 1944. And after me? Nikolay Nikolaevich Bogolyubov. I got it in 1971, and he in 1974. Andrey Dmitrievich Sakharov in 1981. Rasheed Sinyayev last year. And Rasheed Sinyayev, I'm sure he'd get the Nobel prize.

**Remacle:** Tell me about the Lenin Prize. Do you have in physically that I could see? Tell me about receiving that?

**Alferov:** Oh, that was great!

**Remacle:** Did you expect it?

**Alferov:** Yes, absolutely.

**Remacle:** I'm looking at my watch and knowing that you don't have much time and I also have an airplane to catch, so let's make sure we don't leave something out that you really wanted to talk about. Is there something you would like for people a hundred years from now to hear from you?

**Alferov:** I would like to say again that in my opinion in the 60s and at the beginning of the 70s we had very good relations with the American physicists. The development of semiconductor lasers in both countries was the example of an open competition. I arrived to the U.S. and Bell Telephone asked me to visit their laboratory, they showed me their results and we discussed them. I invited them to visit my laboratory—they came to Leningrad, visited my lab, looked at what we were doing. We competed. We

weren't telling everything. Of course, some details we did keep. But nevertheless it was an open competition. And the open competition of these two countries if our countries were still strong enough would have given a lot to the mankind. In my opinion, the biggest tragedy is the collapse of the Soviet Union. Forget the politics. We were a friendly country. When I look now at people from Caucasus or the migrants—they came here to study, it was different then. I think we had a very strong electronic industry in all the 15 republics. It was an electronic empire. There were 3000 enterprises, 400 institutions and designer bureaus and about 3 million people worked there. Russian Federation, Byelorussia and Ukraine were the strongest, but the industry was spread throughout all the republics. Right now only Russia and Byelorussia have it. Then there happened another very important thing. You must mention and maybe visit it some time, Planar Company. Have you heard of it?

**Remacle:** Yes.

**Alferov:** No, you see, that's the one in Minsk.

**Remacle:** Ah, I thought of Pulsar.

**Alferov:** Ah, no, not Pulsar, forget about Pulsar—Planar Company in Minsk. Only three countries produced steppers then, in the 70s. The US, Holland, and the Soviet Union. Planar was situated 7–8 m under the surface of the Earth, with clean rooms and everything perfect. We produced the steppers of the same level as the US, but approximately five times cheaper. Then, I can tell you, I knew Shokin, I knew Kolesnikov very well. We met many times with Kolesnikov, the Minister of Electronic Industry after Shokin. We disagreed frequently, but we had very good relations nevertheless. I remember, once we met in 1985 and he told me, "Zhores, you know, I had a terrible dream tonight." "What dream?" "That Planar did not exist. If Planar does not exist, the electronic industry in the Soviet Union does not exist." It was the dream in 1985. In 1991 it became reality. Planar was a research institute, a designer bureau with the clean rooms technology, and there were enterprises connected with it in Russia and in the Baltic states, maybe 1 0000 people altogether. Now it's only Planar in Minsk and one enterprise in the Vitebsk region, and it's about 1000 people. It stayed only due to the Chinese orders. So, just in general, at the beginning of the 80s main topological size for microelectronics was 1 micrometer. It was the same in Planar technology, in the U.S. and in Japan. And now it's 32 nanometers for Intel, and thinking about 22 and a micron in Zelenograd, and they're only starting to work with 90 nanometers, and they buy old equipment, so we have to forget about the competition. And the people—OK, we still keep the people, and my students work everywhere right now, yes, but, you see, we must compete. It would be good not only for the two countries; it would be good for the whole planet!

**Remacle:** That's one of the things that I think, that hi-tech, semiconductors, computers, networking, telecommunications, all of those industry sectors have helped in many respects to override the politics between the governments and I only hope that they will continue to do so, because I think it would be better, as you say, for everybody.

**Alferov:** Of course, I have a special position, because, you see, the strong electronic industry needed the basic research. If we want to have a strong electronic industry, we need my laboratory. Kolesnikov definitely knew that Alferov laboratory did that and this, and I was getting the money from the Ministry of Electronic Industry, I was getting the equipment from them! And the most important thing, I and my people knew that the country needed us.

**Remacle:** What in your career is the thing that you're the most proud of, that you enjoyed the most?

**Alferov:** I'm the most proud of the heterostructures, and by many different reasons. I came to understand at the very beginning, in 1963, that the heterostructures have changed the electronics. For instance, my boss thought that Zhores was doing research that no one needed. I was absolutely sure that the heterostructures create the new possibilities, and from a certain point of view, OK, silica's cheap and great, but the heterostructures—it's not only the laser, it's not only the solar batteries, it's not only HEMT transistor, high-frequency and so on. It's also the new possibilities to create the new condensate matter labs. And you see, there have been three Nobel prizes in heterostructures. But they did a special kind of quantum hole, fraction quantum hole, and I developed the general idea how to develop heterostructures. Later Leo Isaki, a friend of mine, said he was talking about the super lasers, but I think it concerns all the heterostructures—there are the God-made crystals and the man-made crystals, and those are our heterostructures. And we've changed the spectrum, we came to the quantum well, quantum dots, but the new things will be also created for that. And it's also a new technology and a new physics. And I really was a pioneer, and I did many things there, and that was recognized, and I'm happy that it was recognized, so I got the Lenin Prize, the Nobel Prize, the Kyoto Prize and I got I don't know how many prizes. <Laughs> And I'm also proud that I was the first ahead of the Americans.

**Remacle:** If you were advising, as you must do a lot, if you were advising a young upcoming physicist engineers, what would your advice be to them, how can they be successful, innovative engineer physicists?

**Alferov:** You see, why, for instance, I created this university? This is a special kind of university.

**Remacle:** And we had a nice tour this morning!

**Alferov:** Yes, and we have here only MA and PhD and the schoolchildren in the physico-technical high school. Right now I'm absolutely sure, more than 100%, the future is the union of the condensate matter physics and the biomedicine. And for this union we need a new education system. In order to do some advanced things in this area people must have a very good knowledge of the quantum physics, of the semiconductor physics and technology and to understand well the most important things in modern biology and medicine. Why, for example, my first deputy is a Doctor of medical sciences? Mikhail Dubina, he's young, he's only 40, he's a very talented guy, and he understands physics well. And he has a very

good education in medicine and biology. And he noticed, for instance, he told me that our physics students are faster educated in biology and in medicine than the medical students in physics.

**Remacle:** Oh, that's interesting.

**Alferov:** And this is very important. And, of course, it's very important just to create—definitely there will be the new discoveries, and lots of important new applications, but for U.S. it's very important that this new area develops in our country.

**Remacle:** Is there anything else that we should talk about? Any other subject?

**Alferov:** No, we don't have much time left. I'm very glad to meet you, as, you see, very seldom do I speak like today. Viktor was listening and he knows. Because, you see, all these kind of things, I think about the present situation a lot.

**Remacle:** Why did you say "yes" to the invitation to this conversation?

**Alferov:** You see, it's also the history of semiconductor physics which is very important. And the most important events of this history happened in the U.S. and then in our country, and also in the UK before. Right now there's a good development in Germany, and in whole Europe only the Germany's good. The UK, France, Italy—it's OK, but nothing special, and in Germany the new things, new schools appear, they also develop the universities. The people in our country are talented. We lost a lot during these two decades, because, you see, in the last two decades there was the development of technology. The most important things in physics, in semiconductor physics happened earlier. Majority of the results where I was the pioneer were realized on the large scale in these two decades. But in the combination of the physics and biology some new phenomena will be discovered very soon. The basis has already been created, because for U.S. the basis was created in the first half of the XX century, the quantum physics. For the molecular biology it was the 60s and the 70s when the basis was created. But right now there goes a very fast synthesis of physics and technology in medicine and biology. That's why, for instance, Roger Comberg, when I was appointed as a chairman of Skolkovo scientific council and they asked me to choose a co-chairman, I chose Roger, because he works in this area where both of U.S. can help each other.

**Remacle:** I still am curious, though, when you thought about all the things you have to do every day, how busy you are with things that are more important than sitting, talking to me about...

**Alferov:** No, talking with you was a lucky chance. I'm occupied with so much absolutely tedious things!

**Remacle:** But I'm really serious about it: what it was that you wanted to convey that you made time in your schedule for this conversation?

**Alferov:** No, you see, I consider it very important. Again, in my opinion, in spite of the many disasters that have happened in our country it's still the public opinion that counts, not all but of some public in the U.S. and in Russia, and it's very important for the world.

**Remacle:** I agree. Well, thank you so much for taking the time, because I hope that when you come to the U.S. you have my business card, you have John Hollar's, I'll give it to you, he's the CEO of the museum, we would love to give you a private tour of the museum and invite you to come speak at a public session of some kind, so please put that in your mental calendar. OK, thank you!

**Alferov:** Thank you!

END OF INTERVIEW