PNIN Switches  Feb 24 '58

5. PNIN or PNPN Switch, the
following effects will be important:
1. Maximum open voltage
2. Minimum switching current
3. Maximum "on" current

In the PNIN or PNPN operating by
conduction modulation, as noted in memo of
3-12-58, Increasing resistivity of Pt region
will increase the open voltage permissible. By
increasing resistivity of middle regions, considerable
fringing will take place, and consequently a higher
current density will flow near the base contact.
Thus, a small part of the total area can be used
to turn the switch on; thereafter the entire
area will be required for current carrying. Thus,
the current necessary for triggering will be
essentially independent of plate area, but the
total current which may be used will be
proportional to area.

Design
Let {eq}I_{on} \neq \text{arbitrary design}

Effectives
PB Haye  Mar 24, 58
V_max = 300 volts
I_max = 100 amps
I trigger = 10 mA

Breakdown field is achieved one of the order of 3 x 10^5 V/cm, corresponding to space charge of about 10^{12} electrons/cm^3. The total voltage across the junction, assuming step-function density, depends on one side to one half of the magnesium field times the width of the space-charge region.

E_max x W = 600 V
3 x 10^5 W = 600
W = 600 / 3 x 10^5 = 3 x 10^{-5} cm^2 = 30 µm

Drifting density & 5 x 10^{-5} cm / µsec

Area necessary for power dissipation:

Thermal Conductivity of Silicon 3
1 PC/watt - cm.

For 50 µm thick wafer:
\[ R_A = \frac{5 \times 10^{-5}}{A} °C/watt \]

Furthermore, assuming a copper heat sink.
The thermal resistance will be approximately
$\text{Kinic}^\circ\text{C/watt}$

For 100 Ampere case, assuming a voltage
Keep at 24 volts.

Power = 300 watts.

Limiting case above 50° C line, the thermal resistance must be held to 6° C/watt.
A radius of 1 in. meets this easily, perhaps
we could get by with 1.5 mm. diame.

Resistivity of outer layers - 0.012, inner 0.014.

Final design.

[Diagram of design with annotations]
100 MIPS oscillator. - object: smooth output - Design.

Oscillator Efficiency:

[Graph showing efficiency curve]

Since make a 300 mips transistor (lowness) one should be able to get 100 mips beta efficiency - looks high.

Problem will be small geometry - in the small geometry, the main limitation lies in the size indexing to be done so that the oxide mask and contact areas are in proper registration.

This idea occurs. Mask says a part with the electroplating which will serve as a mask against the diffusion of the emitter and will also serve as contact:

Collector  
N diffusion

Typical characteristics of the smaller layout come 5–12 in.

The source resistance is undesirable, but, might be tolerable.

If the evaporated film were reacting to the silver.

Dr. Fein 25
Prior to alloying, as well ought be the case, this often could be desired so no plating renewed occurring to immediate vicinity there is a possibility for small geometry.

For instance: in K.P.

Sequence:

1. Form difference
2. All evaporate
3. With bias as shown, plate then remove metal without should not plate near terminals


Poor oscillator efficiency -

\[
\begin{align*}
P_{oc} & \rightarrow \text{Transistor} \rightarrow P_{out} \\

P_{out} + P_{feedback} &= 6.7 \text{W} \\
P_{out} &= (6-1)P_{+} \\
Class Bc: P_{oc} &= \frac{3}{2}(P_{+} + P_{t}) \\
P_{+} + P_{t} &= P_{o}(1 + \frac{1}{6-1}) = P_{o}\left(\frac{5}{6-1}\right) \\
Efficiency &= \frac{P_{out}}{P_{oc}} = \frac{P_{o}-}{P_{o}} (\%) = \frac{1}{2} \left(\frac{6-1}{6}\right)
\end{align*}
\]

\[
\begin{align*}
S' &= 6 - \frac{G_0(1 - 4 \beta_{max})}{2} \\
\beta_{fp} &= \frac{1}{2} \left(\frac{s_{fp}}{G_0}\right) \frac{1}{2} \left(\frac{G_0(1 - 4 \beta_{max})}{6}\right) \\
&= \frac{G_0}{6} > 1
\end{align*}
\]
FEB 26. Analysis from preceding page should be modified to account for less than 50% efficiency at low voltages, but is not in great error.

For PNP, efficiency of 40% or more have been realized.

In general, for high frequency power oscillator at 1/3 max, 25% efficiency. This seems a reasonable place to work.

For 100 mops oscillator, 5 watts -- we would need a 30 watt unit with f max of 200 mops.

This would give:

\[ \text{8-10 watts at 50 mops.} \]
\[ \text{3-5 watts at 100 mops.} \]

Range in design:

\[ f_X = 50 \text{ mops.} \]
\[ L = \frac{2.5 \times 10^8}{2 \times 4 \times 10^{-10}} = 6.25 \times 10^{-9} \]

\[ \frac{f_c = 100 \text{ mpps, } R_o = 63}{4} \]

This appears to be the range to work in.

Size necessary for power:

Full PNP unit .020 x .15 cm for 10 watts.

Use .040 x .16 cm = 15 mils x 60 mils.

Another 3x this area would be safer!
Problems: 1) Induced Tetrode, to work out
2) Tetrode structure: 16 grounded.
3) DC feedback in internal Tetrode.

The general problem to work out here is this: how much does internal tetrode help in reduced high frequency power transduction.

Part 2: DC current distribution.

\[
\begin{align*}
\text{Assume:} & \quad I_x = I_{0x} e^{-\frac{x}{\lambda}} \\
\text{Sheet resistance}\ & \rho_s
\end{align*}
\]

\[
\frac{dV}{dx} = \frac{\rho_s I_{0x} e^{-\frac{x}{\lambda}}}{\lambda} (1-\alpha)
\]

Linear geometry if \( d \) with \( I_x \).
Power oscillator

Output Impedance

\[ L_0 = \frac{1 - \frac{f_0^2}{f_c^2} + \frac{f_0^2}{f_c^2}}{\omega_0 (\omega/f_c)} \approx \frac{L_0}{\omega_0} \text{ for Max Gain} \]

Approximations

1. \((1 - f_0^2) < (\omega/f_c)^2\)
2. \(f_0 = \frac{1}{\omega_0}\)

Then

\[ L_0 = \frac{\omega}{\omega_0 + \omega C_i} = \frac{\omega C_i}{\omega_0} \]

Therefore, for space quoted:

\[ C_i = \frac{300}{\mu}\text{mF, 60V, 250mA} \]

\[ \frac{1}{\omega C_i} = 250 \text{ meps}, \frac{1}{2\pi C_i} = 400 \text{ meps} \]

\[ \frac{1}{2\pi C_i} = 250 \times 10^6 \]

\[ C_i = \frac{300}{11 \times 250 \times 10^6} = \frac{44 \times 10^6}{11 \times 250} \mu\text{F} = 2.1 \mu\text{F} \]

Total capacitance, say 4x or 10x at 28Vdc.

Feedback capacitance \( < 3 \mu\text{F} \).
<table>
<thead>
<tr>
<th>Geometry</th>
<th>Diameter (mils)</th>
<th>Area (cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emitter</td>
<td>15</td>
<td>$1.1 \times 10^{-3}$</td>
</tr>
<tr>
<td>Collector</td>
<td>30</td>
<td>$4.4 \times 10^{-3}$</td>
</tr>
<tr>
<td>Inner base</td>
<td>30.5</td>
<td></td>
</tr>
<tr>
<td>Waler Thickness</td>
<td>50μ</td>
<td>1 cm</td>
</tr>
<tr>
<td>Thickness</td>
<td></td>
<td></td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{ext}$</td>
<td>18</td>
</tr>
<tr>
<td>$D_{int}$</td>
<td>15</td>
</tr>
<tr>
<td>$L_{ext}$</td>
<td>15</td>
</tr>
<tr>
<td>$L_{int}$</td>
<td>15</td>
</tr>
<tr>
<td>$W_x$</td>
<td>4.6</td>
</tr>
<tr>
<td>$W_y$</td>
<td>4.6</td>
</tr>
<tr>
<td>$B_{V, bs}$</td>
<td>120-160</td>
</tr>
<tr>
<td>$B_{V, ps}$</td>
<td>12-17</td>
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<tr>
<td>$R_{D}$</td>
<td>12</td>
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<tr>
<td>$R_{on}$</td>
<td>45</td>
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<tr>
<td>$W_x$</td>
<td>5.7</td>
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<tr>
<td>$W_y$</td>
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<tr>
<td>$C_{pi, lef}$</td>
<td>7.8</td>
</tr>
<tr>
<td>$C_{pi, righ}$</td>
<td>7.8</td>
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<tr>
<td>$f_{max}$</td>
<td>158</td>
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<tr>
<td>$F_{x, lef}$</td>
<td>2.19</td>
</tr>
<tr>
<td>$V_x$</td>
<td>8.3 x 10⁻⁴</td>
</tr>
<tr>
<td>$V_y$</td>
<td>1.6 x 10⁻⁴</td>
</tr>
<tr>
<td>$V_{x, y, 200}$</td>
<td>1.8</td>
</tr>
</tbody>
</table>

For $5 = 2cm$:

- $V_{off} = 23 x 2 \text{ V at } 20\mu A$
- $4 x 100 = 4.6 \text{ W at } 5.4 = 115 \text{ ohms}$
- $\eta = \frac{V_{off}}{V_x} = 41\%$

For $C_{pi, righ} = \eta = \frac{4}{5} \times 41 = 32.8\%$
Also necessary for power dissipation:

From hemispheres: \( P \propto \frac{1}{R^4} \)

\[ P = \frac{\pi}{6} \cdot P_0 \]

\( T \) silicon = 200°C/100°C
8.4 W/cm²/°C

For \( R = 7 \) mile = 1.1270 cm,

\[ P_0 = 2 \cdot 10^9 \cdot \frac{2.74 \times 10^{-7}}{2.74} = 208 \text{ W/m²} \]

\( C_0 = 1.8 \)

Assuming 50 μm wafer,

\[ P_r = \frac{I}{A} = \frac{5 \times 10^{-3}}{0.05 \times 0.01} = 100 \text{ °C/W} \]

Semiconductor on black:

\[ P_r = \frac{1}{3} \times 1.2 \times 10^9 \times 0.01 \times 0.01 \times 0.01 = 95 \text{ °C/W} \]

Total resistance = 50 °C/W.

Even if, no additional heating will raise the total resistance.

For simple geometry, area cannot be smaller than the other given. This is pushing it to the limit. Also, the thermal resistance of the silicon is small compared to that of the copper. Silver is only 10% higher.

For this linear and a capacitance of 1 nF/pL, the space charge region would have to be:

\[ C = 10^{-12} \text{ F} = 10^{-12} \times 1.1 \times 10^{-5} \]

\[ d = 11 \mu \text{m} \]

 Transit time for space charge region:

\[ t = \frac{10^{-5}}{10^{-12}} \approx 10^{-7} \text{ sec} \]
The output capacitance does not permit a 2W resistor to be the best compromise to get power out from a 28V DC supply. For this, it would be better to install a design to breakdown voltage.

Design for 28V DC.

\[ E_{max} = 8 \times 10^5 \text{ Volts} \]

\[ E_{dc} = \frac{E_{max}}{10} = 10^5 \]

For 70V Breakdown, \( E_{peak} = 7 \text{ V} \)

\[ C_{peak} \approx \frac{1}{70} \text{ mF} \]

\[ M \approx \frac{C_{peak}}{10} \approx 0.36 \times 10^{-15} \times 280 \text{ microfarads} = 36 \text{ pF} \]

Assuming 10 mA load, and 30 mA - 2 V drop, adding say 5 V for lamp load - 7 volts.

\[ \eta = \eta_0 \left( \frac{C_{peak}}{C} \right) \]

Assuming \( C = 3 \), \( \eta = \frac{1}{2} \eta_0 = \frac{1}{2} \times 15\% = 7.5\% \)

For 35\% efficiency gain = 8 \( = 10 \) to 1.28 above.

for 35\% eff \( = 3.53 \text{ watts} = \frac{1}{118} \text{ watt out} \)

28V DC source 118 mA.
Internal Tides - Effects on tides, etc. - P.8. cont.

1. Infinite, semi-infinite geometry.

2. Cylindrical - is cylindrical.

\[ r \cos \theta = \frac{c}{v} \left( 1 - \frac{1}{2} \right) \theta \]

Linear case:

\[ \frac{dV}{dr} = \frac{c}{\sqrt{r^2 - c^2}} \left( 1 - \frac{1}{2} \right) \theta 
\]

Cylindrical:

\[ \frac{dV}{dr} = \frac{c}{\sqrt{r^2 - c^2}} \left( 1 - \frac{1}{2} \right) \theta 
\]

\[ \frac{d^2V}{dr^2} = \frac{c}{\sqrt{r^2 - c^2}} \left( 1 - \frac{1}{2} \right) \theta 
\]

Let \( r = \theta \)

\[ \frac{d\theta}{dr} = \frac{c}{\theta} \]

\[ \frac{d^2\theta}{dr^2} = \frac{c}{\theta^2} \]

Let \( \theta = \ln \frac{c}{\theta} \)

\[ \frac{d\theta}{dr} = \frac{c}{\theta} \]

\[ \frac{d^2\theta}{dr^2} = \frac{c}{\theta^2} \]

\[ V = \frac{c}{\theta} \]
\[ \frac{dz}{dt} = \frac{dy}{t} \]

\[ \int \frac{dy}{y \sqrt{2y + a}} = \int \frac{dy}{\sqrt{y \sqrt{2y + a}}} \]

\[ \sqrt{y + a} = \frac{3}{5} \left( \frac{2y + a}{2} \right)^{\frac{3}{2}} - \frac{3}{2} \frac{(2y + a)^{\frac{3}{2}}}{2} \]

Check:

\[ \frac{dx}{dy} = \frac{dy}{dz} \]

\[ \frac{d^2x}{dy^2} = \frac{d}{dy} \left( \frac{dy}{dz} \right) \]

\[ \frac{d^2x}{dt^2} = \frac{1}{y \sqrt{2y + a}} \left( \frac{dy}{dt} \right)^2 = y^2 \]

Let \( p = \frac{dy}{dt} \)

\[ p' = \frac{d}{dt} \left( \frac{dy}{dt} \right) = \frac{dy}{dt} \]

No help.

Reference to eigenvalue eqns.:

\[ \frac{d^2V}{dx^2} = kQ_0 e^{-\frac{2k}{\sqrt{t}} (1-x)} \]

To reduce to \( y'' = c^2 z'' \):

\[ \text{let } z = e^{\frac{2k}{\sqrt{t}} x} + \ln a \]

\[ z'' = \left( \frac{k}{2t} \right)^2 c^2 \]

\[ e^c = a e^{-\frac{2k}{\sqrt{t}}} \]

\[ c = \left( \frac{k}{2t} \right)^2 \]

Then \( a = \frac{Q_0}{k} \left( \frac{k}{2t} \right)^2 \)

This seems to be a solution for linear case ok. Fourier:

Inverse function perhaps difficult. Plot a way.
Boundary conditions

at \( x = -w \), \( \frac{dy}{dx} = 0, \ \frac{d^2y}{dx^2} = w \)

at \( x = 0 \), \( \frac{dy}{dx} = f(y, \rho_0) \)

\[ dx = \left( \frac{1}{a^2} (\sigma y + a)^2 + \frac{1}{\sqrt{2\pi}a} \right) dy \]

\[ s y(w) + a = \frac{a^w}{a^w} \]

\[ y(w) = \frac{a^w}{a^w} - \frac{a^w}{a^w} \]

Plan of Calculations
1. Calculate \( J(1) \)
2. Calculate \( \frac{dJ}{d\rho} \) \( \text{at} \) \( \rho = \rho_0 \)
3. Calculate \( \frac{dJ}{d\rho} \text{at} \) \( \omega \) (small \( \rho \), linear) by calculating \( \text{ro} \) and interpolating \( \frac{dJ}{d\rho} \text{at} \) \( \omega \).
4. Calculate \( \text{ratio} \) \( \text{at} \) \( \omega \) value.

What do you think? Feedback.

Gain is when
\[ \beta = \frac{d\Delta T}{dV(B)} = \frac{dV(B)}{d\Delta T} \text{ for constant} \]

If this is correct interpretation, we should be able to predict finite formula correctly
\[ \beta = \frac{1}{V} \]

Ask Giner about this.

Look up calculations in circular geometry.
March 7 59

References on emitter current distribution:
filed on 5X71
BTL Eng. Serv. #68 air 25
D.H. Looney

Simple-minded approach to fringing:

1. Characteristic length \( l = \left( \frac{I_b}{2 \pi \sigma R_e} \right)^{0.5} \frac{1}{\sqrt{\pi KT}} \)

In our case:

\( I_b = 10^{-2} \text{amps} \)

\( R_e = 800 \Omega \)

\( \sigma = 0.575 \text{ cm} \)

\( l = \left( \frac{800 \times 10^{-2}}{6.28 \times 0.575} \right)^{0.5} \frac{1}{\sqrt{\pi KT}} \)

\( = \frac{1380}{7} = 196 \mu \text{m} \)

Collector spreading resistance:

\( R = \frac{1.5 \text{ cm}}{3.5 \times 0.575} \)

\( = 8.1 \) Does not look too bad

Base spreading resistance:

Under emitter:

\( R_s = \frac{10}{6.28 \times 0.575} \)

\( = 0.0312 \Omega \)

\( = 3 \Omega \)

Series \( r \) in base:

\( \approx 5 \)

\( R_{total} = 8 \)
Current density:

\[ J = \frac{\mu}{e.25 \times 0.035 \times 0.007} = \frac{1.25 \times 10^3 \text{ amp/cm}^2}{\text{cm}^2} \]

Characteristic current for low conductivity modulation.

Carrier list in base:

\[ J = \frac{q \cdot D \cdot \delta}{W} \]

\[ \text{gradient} = \text{Cmax} \times 5000 \]

\[ J = \frac{q \cdot D \cdot \delta}{W} = 16 \times 10^{-9} \times 7.5 \times 5 \times 10^9 \text{ cm}^{-1} \]

\[ \mu = 2 \times 10^7 \text{ cm}^2/\text{V.s} \]

\[ D = 5 \times 10^{-4} \text{ cm}^2/\text{s} \]

\[ n = 7.5 \]

\[ n = 560 \text{ cm}^2/\text{cm}^2 \]

So, this range is getting dangerous for low frequencies.
March 1958.

Structuring problem:

Here is another approach to the indexing problem which might work.

On oxide removal, we leave some relief on the surface. After further oxidation, or perhaps erosion by HCI in the diffusion operation, this relief will still be present. Perhaps a resist could be found which had enough surface tension that it would pull away from these sharp corners:

Point of attack.

If so, acid etch would attack first in the area where it is desired to remove metal causing emitter-base shorts. This being the case, no reindexing would be necessary. The oxide etching would settle the geometry, both of n+p areas and of contact areas.
Discussion this noon with Dean Watkins and Dick Johnson about, among other things, parametric amplifiers. Watkins' analysis of the situation is this: Ferrites, although of proven low noise, are narrow band and require liquid helium reservoirs. Ferromagnetic parametric amplifiers are tricky in alignment, etc. The semiconductor diodes and the electron beam resonant parametric capacitors seem to hold the most promise.

The requirements on the semiconductor diode are:

1. High Q, i.e., low losses.
2. Low interference feed arrangement.
3. Low loss package. (Not ceramic, too high dielectric — low loss glass. 7073)
4. Stable to ± in small size. See note 7053.
Basic principle of amplifier.

\[ w_3 = w_1 + w_2 \]

Pump at \( w_3 \) causes no resistance across Tank \( w_1 + w_2 \). Power can be taken out at Either \( w_1 \) or \( w_2 \).

This amplifier is reciprocal: some isolation is needed, or perfect matching so reflections are not amplified.

Iterated Amplifier:

Require \( V_{in} = V_{in} = V_{in} \) for this to work.

These equal phase velocities are more easily achieved in coaxial.

May 17: Watkins phoned to give these numbers:

- BTL capacitor for parametric amp.
- \( Q = 2000 \) mps.
- \( 5 \text{ to } 10 \)
- \( C \sim 3 \text{ pF} \) near zero bias.
We also decided the possibility to use doubling
by the use of 2 capacitors back to back:

![Diagram]

This gives effective drive of twice the frequency
actually used. A ground may suffer.

Mounting similar to 1N23, with small
pin at both ends.

April 8 '58.

Problem of Emitter Capacitance.

In the case of the forward biased emitter junction,
the emitter capacitance becomes a little difficult to
calculate. Finally, the straight transition capacitance
is important, but one can no longer examine
only the large area capacitance, but one must also consider
the mobile charges in the space charge region. This
argument holds for the diffusion capacitance as well:
it is due to mobile charges.
Diffusion capacitance.

Assuming a given distribution of Na–Na+ in the
space, and assuming $J_p \ll J_n$
Eqs. for current flow.

$$\frac{J_{n+}}{\bar{y}} = \frac{D_n}{\sqrt{\pi t}} + n p N \frac{\partial}{\partial x}$$

$$\frac{J_p}{\bar{y}} = \frac{D_p}{\sqrt{\pi t}} + \mu_p E = 0$$

$$\rho = N_p (x) + n (x)$$

$$\frac{\partial \rho}{\partial t} = \frac{\partial^2 \rho}{\partial x^2} + \frac{\partial E}{\partial x}$$

$$E = \frac{\rho}{\varepsilon} \frac{\partial}{\partial y}$$

$$D = \frac{\varepsilon}{\mu_p}$$

$$\frac{J_{n+}}{\bar{y}} = \frac{D_n}{\sqrt{\pi t}} + \frac{D_p}{\sqrt{\pi t}} \frac{\partial}{\partial x}$$

$$= D_n \left[ \frac{\partial n}{\partial y} + \frac{\partial N}{\partial y} \left( \frac{\partial n}{\partial y} + \frac{\partial N}{\partial y} \right) \right]$$

$$= D_n \left[ \frac{\partial n + N}{n + N} \frac{\partial n}{\partial y} + \frac{n}{n + N} \frac{\partial N}{\partial y} \right]$$

$$\left( \frac{\partial \rho}{\partial y} \right)_x = \left( 1 + \frac{n}{N} \right) \frac{\partial n}{\partial y} + \frac{n}{n + N} \frac{\partial N}{\partial y}$$

Scheme for integrating:

$$\frac{\partial \rho}{\partial y}$$

Set up as difference equation:

$$\frac{J_{n+}}{\bar{y}} = \left( 1 + \frac{N}{N+N_p} \right) \frac{n_{i+1} - N_p}{\Delta x} + \frac{N_p}{N+N_p} \frac{n_{i+1} - N_p}{\Delta x}$$

Known: $N_p, N_n, N_{n+1}, \Delta x$

Solve for $n_{n+1}$

$$n_{n+1} = \left( \frac{N_p + N_n}{N_n + N_p} \right) \Delta x \left[ \frac{J_{n+}}{\bar{y}} + \frac{3 n_{n+1} - N_p}{(N_p + N_n) \Delta x} \right]$$

$$\Delta x = \frac{n_{n+1} - N_p}{N_p + N_n}$$
\[ n_{t+1} = n_t + \frac{r_t + N_t}{S_t + N_t} \cdot \frac{S_t}{S_t + N_t} \cdot \frac{\Delta n_t}{S_t} \cdot (N_{t+1} - n_t) \]

Perhaps exponential could be used:

\[ N_t = A e^{-\alpha t} + B e^{-\beta t} \]

\[ \frac{dN_t}{dt} = -\alpha A e^{-\alpha t} + \beta B e^{-\beta t} \]

L许可, then p. Reference your latter.

We can also calculate transit time from \( \frac{dN_t}{dt} = 0 \).

In order to make a general so possible, divide through by \( \frac{dN_t}{dt} \):

\[ \frac{N_t}{N_0} = \frac{\frac{dN_t}{dt}}{\frac{dN_0}{dt}} = \frac{\frac{dN_t}{dt}}{\frac{dN_0}{dt}} \]

Results can still dependent on D value is not a constant (e.g. p.) However, this should be reasonably good indication of transit time, seeing nothing

appropriate to maximum delay density. Work out for values of \( \frac{N_t}{N_0} = \{1, 2, 10\} \). To calculate transit time, the time air passing through the

\[ \text{space change region must be added}. \]
Consider:
1. App transmitter.
   2. Ensure \( \text{net. in} = \text{net. out} \).

Approach: Acquire Electrostatic Neutrality.
2. \( J_0 = J_p \).

\[
\frac{J_0}{J_p} = \frac{\xi Q}{\xi p} \frac{dT}{dy} + \frac{\xi p}{\xi P} E = \text{Const.}
\]

\[
\frac{J_0}{J_p} = \frac{\xi Q}{\xi p} \frac{dT}{dy} - \frac{\xi p}{\xi P} nE = 0.
\]

\[
n + N(\infty) = \rho.
\]

\[
\frac{dn}{dy} + \frac{dN(\infty)}{dy} = \frac{dn}{dy}
\]

\[
\frac{J_0}{J_p} = \frac{\xi Q}{\xi p} \frac{dT}{dy} - \frac{\xi p}{\xi P} (\frac{dn}{dy} - \frac{dN(\infty)}{dy}) = 0.
\]

\[
E = \frac{\xi T}{\xi P} \left( \frac{dn}{dy} - \frac{dN(\infty)}{dy} \right) / (\rho + N(\infty)).
\]

Then,
\[
\frac{J_0}{J_p} = \frac{\xi Q}{\xi p} \frac{dT}{dy} + \frac{\xi p}{\xi P} (\frac{dn}{dy} - \frac{dN(\infty)}{dy})
\]

\[
\frac{J_0}{J_p} = \frac{\xi p}{\xi P} \frac{\alpha(x)}{\alpha(x) + \beta(x)} \frac{dT}{dy} - \frac{\xi p}{\xi P} \frac{\beta(x)}{\alpha(x) + \beta(x)} \frac{d(\alpha(x))}{dy}
\]

\[
\frac{dT}{dy} = \frac{\alpha(x) + \beta(x)}{\alpha(x) + \beta(x)} \left[ \frac{dP}{d\alpha(x)} \frac{d\alpha(x)}{dy} \right]
\]

Lacks OK.
Calculations on actual structures

C02 $5 \times 10^{-6}$

C02 $5 \times 10^{-6}$

$x_0 = 3.4 \mu m$

$x_c = 1.6 \mu m$

CuFe $5 \times 10^{-6}$

From the above:

\[
\sqrt{\frac{dt}{x}} = \frac{1}{\mu m}
\]

at $2.6 \mu m$, $C_0 = 3.3 \times 10^{-7}$

\[
\frac{C_c}{C_0} = 0.006
\]
Calculation for sample case.

Assume \( N_0 = 0 \) when \( x < w \)
\[ N(x) = -N_0 \quad x > w. \]

For \( x < w \),
\[ \frac{dN}{dx} = \frac{\frac{1}{2} p}{D_p}. \]

Then \( P(w) = \frac{1}{2} \frac{dN}{dx} \) when \( x > w \)

For \( x > w \),
\[ \frac{dP}{dy} = \frac{P(x) + \frac{N_0}{w}}{P(x) + \frac{N_0}{w}} \frac{dN}{dx}. \]

We have to consider the term \( \frac{dN}{dx} \) which under ideone approximation is significant at \( x = w \).

However, to get order of magnitude of minority carrier density at magnitude of base doping one might write
\[ P = \frac{1}{2} \frac{p}{D_p} w. \]

Conversely, knowing \( p \) at this point, which will vary nearly linearly with the emitter we can calculate the current density.

1. Assume doping density as follows:
   \[ \text{Slope} \times 10^{15} = 10^3 / \mu. \]

Voltage drop across junction for equilibrium is equal to difference in Fermi levels for the material at the edge of the space charge region.
\[ I(\alpha) = 3 \frac{R_i^2}{n_{max}} \frac{D_{0i}}{W} \]

For:
- \[ n_i = 3 \times 10^{10} \]
- \[ W = 2 \times 10^4 \]
- \[ n_{max} = 10^7 \]
- \[ \frac{d}{d} = \frac{e^{2.5 \times 10^3}}{100} \]
- \[ \frac{R_i}{n_{max}} = 6 \times 10^3 \]
- \[ 3 \frac{R_i^2}{n_{max}} \frac{D_{0i}}{W} = \frac{e^{2.5 \times 10^3}}{100} \]
- \[ I_0 = 4.7 \times 10^{-10} \text{ amp/arc}^2 \]

For \( 10 \text{ product} \):
- \[ n_i = 3 \times 10^{10} \]

\[ \mathbf{u} = \int \frac{V}{2} \]
- \[ 0.01 \text{ at 0.01 A} \]
- \[ 0.5 \text{ at 0.05 A} \]
- \[ 0.1 \text{ at 0.01 A} \]

\[ \mathbf{e} \]
- \[ 0.01 \text{ at 0.01 A} \]

\[ \mathbf{e} \]
- \[ 0.01 \text{ at 0.01 A} \]

\[ \mathbf{e} \]
- \[ 0.01 \text{ at 0.01 A} \]

\[ \mathbf{e} \]
- \[ 0.01 \text{ at 0.01 A} \]
Potential vs. sp. chg. width.

\[ \frac{V}{z} = \int \frac{e}{w} \]

\[ \begin{align*}
\nabla^2 V &= -\frac{\rho}{\epsilon_0} \\
\nabla V &= E = \frac{\rho}{\epsilon_0} \\
V &= -\frac{\rho x^2}{2\epsilon_0} + \frac{\rho w^2}{2}
\end{align*} \]

\[ \Delta V = 5 V(w) = \frac{8E_0^2 - 9}{3} \]

\[ E_{ext} = 2 \times 10^6 \times 10^{-12} a \cdot w^3 = 2 \times 10^7 w^3 \quad (w \approx \mu) \]

**Equilibrium drift vs. voltage**

\[ Q = E_{max} \tau \frac{E(0)}{2} = \frac{8E_0^2 w}{3} \]

\[ = 2 \times 10^{-9} \times 10^{12} \quad w^2 = 8 \times 10^{-6} \quad w^2 / \mu (w \approx \mu) \]

\[ Q = 8 \times 10^{-6} \left( \frac{V_0 - V}{17} \right) \frac{2}{\mu} \text{ coulombs} \]

\[ Q \rightarrow I \]

\[ I = I_0 e^{-\lambda x} \quad (\text{no Land, modulation}) \]
\textbf{Not valid - expected charge must dominate.}

\begin{align*}
Q_{\text{vol}} & = 3.6 \times 10^{-7} \\
Q_{\text{com}} & = 0
\end{align*}
Injected density in sp. ch. region:

1. Assume constant current through sp. ch. region.

2. Net Calc:
   
   Plot at

Approx. feed (not considering mobile carriers at outlet) Dbye length ~ sp. ch. width.

Forward Time

Dbye length

Order of magnitude: Calculation of injected charges:

<table>
<thead>
<tr>
<th>V</th>
<th>( e^{4/3} )</th>
<th>( W )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>1.38 ( \times 10^{-2} )</td>
<td>1.58 ( \times 10^{-5} )</td>
</tr>
<tr>
<td>0.6</td>
<td>1.38 ( \times 10^{-2} )</td>
<td>1.63 ( \times 10^{-5} )</td>
</tr>
<tr>
<td>0.85</td>
<td>91.5</td>
<td>4.82 ( \times 10^{-5} )</td>
</tr>
<tr>
<td>1.7</td>
<td>3530</td>
<td>1.8 ( \times 10^{-5} )</td>
</tr>
</tbody>
</table>
Apr. 14. Check on previous calculations.

Constants: \( U = \text{25 M.W.} \), \( \tau = 1.06 \times 10^{-4} \text{ sec} \), \( M = 3 \times 10^{-7} \text{ lb} \)

\[
\Delta V = -\frac{v}{\tau} \text{ vs. } \frac{v}{\tau}
\]

\[
\Delta V = \frac{q}{2} \text{ vs. } \frac{q}{2}
\]

\[
\Delta V = \frac{q}{2} \left( \frac{1}{\tau} \right)
\]

\[
\frac{U}{v} = \frac{5.06 \times 10^{-2} \text{ W}^2}{5 \times 10^{-11} \text{ W}^2} = 2.5 \times 10^{-9} \text{ W}^2 \text{ in cm}^2
\]

\[
C = \frac{10 \times 10^{-6} \text{ cc}^2}{\frac{10}{\text{cc}}^2} = \frac{3 \times 10^{-6} \text{ cc}^2}{\text{cm}^2} = \frac{5 \times 10^{-9} \text{ cc}^2}{\text{cm}^2}
\]

\[
\text{Equation Force Load}
\]

\[
E + E_1 = \frac{E}{2} \text{ vs. } \frac{E}{2}
\]

\[
\frac{E}{2} = \frac{E}{2} \text{ vs. } \frac{E}{2}
\]

\[
3 \times 10^{-6} = 0.5 \text{ cc} \text{ vs. } 3 \times 10^{-6}
\]

\[
10^{-5} = 1 \text{ cc} \text{ vs. } 10^{-5}
\]

\[
5 \times 10^{-5} = 5 \times 10^{-5} \text{ cc} \text{ vs. } 1.5 \times 10^{-5}
\]

\[
2 \times 10^{-5} = 0.2
\]

\[
E = 2 \times 10^{-5} \text{ cc} \text{ vs. } 2 \times 10^{-5}
\]

\[
E = 2 \times 10^{-5} \text{ cc} \text{ vs. } 2 \times 10^{-5}
\]

\[
\begin{align*}
&x \quad \text{ac} \quad \frac{d^2}{d (\text{ac})^2} \quad \left( \frac{d^2}{d (\text{ac})^2} \right) \times 10^{-6} \text{ in}^3 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 6.33 \times 10^{-6} \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 5.25 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 5.222 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 6.8 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 5.245 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.78 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 4.2 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.7 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.72 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
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&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74 \\
&5 \times 10^{-6} \text{ cc} \quad 5 \times 10^{-6} \text{ cc} \quad 3.74
some calculation for skip test

\[ V \Delta V = 0.02 \text{ ohms} \]

\[ V \Delta V = 0.02 \times 1.0 \times 10^{-5} \text{ W} \]

\[ V = 1.0 \times 10^{-5} \text{ W} \]

\[ Q = 1.0 \times 10^{-5} \text{ W} \]

<table>
<thead>
<tr>
<th>W (ohm)</th>
<th>V (ohm)</th>
<th>Q (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0001</td>
<td>0.0075</td>
<td>1.64 \times 10^{-5}</td>
</tr>
<tr>
<td>1.0004</td>
<td>0.0002</td>
<td>3.2 \times 10^{-5}</td>
</tr>
<tr>
<td>1.0009</td>
<td>0.0600</td>
<td>4.8</td>
</tr>
<tr>
<td>1.0116</td>
<td>1.21</td>
<td>6.4</td>
</tr>
<tr>
<td>1.0025</td>
<td>1.18</td>
<td>6.0</td>
</tr>
<tr>
<td>1.0036</td>
<td>1.72</td>
<td>9.6</td>
</tr>
<tr>
<td>1.0064</td>
<td>3.70</td>
<td>4.7</td>
</tr>
<tr>
<td>1.0076</td>
<td>4.78</td>
<td></td>
</tr>
<tr>
<td>1.081</td>
<td>6.12</td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>7.55</td>
<td>1.6 \times 10^{-7}</td>
</tr>
<tr>
<td>1.1012</td>
<td>9.13</td>
<td>6.7 \times 10^{-6}</td>
</tr>
<tr>
<td>1.0182</td>
<td>9.46</td>
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</tr>
<tr>
<td>1.0144</td>
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<td>4.48</td>
</tr>
<tr>
<td>1.078</td>
<td>5.9</td>
<td>4.98</td>
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<tr>
<td>0.9</td>
<td>3.8</td>
<td>3.8</td>
</tr>
<tr>
<td>0.7</td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td>0.6</td>
<td>1.8</td>
<td>1.8</td>
</tr>
<tr>
<td>0.5</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Voltage</td>
<td>Vapped</td>
<td>Current</td>
</tr>
<tr>
<td>--------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>1.836</td>
<td>1.746</td>
<td>1.72</td>
</tr>
<tr>
<td>1.772</td>
<td>1.23</td>
<td>1.5</td>
</tr>
<tr>
<td>3.72</td>
<td>3.98</td>
<td>16.6</td>
</tr>
<tr>
<td>8.06</td>
<td>7.6</td>
<td>52.2</td>
</tr>
</tbody>
</table>

Step 2: at zero base. \( V = 8.82 \text{V} \) \( Q = 18.25 \)

<table>
<thead>
<tr>
<th>Unit</th>
<th>Vapped</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.7</td>
<td>1.72</td>
</tr>
<tr>
<td>3.02</td>
<td>3.04</td>
</tr>
<tr>
<td>4.72</td>
<td>4.76</td>
</tr>
<tr>
<td>5.9</td>
<td>5.92</td>
</tr>
<tr>
<td>6.8</td>
<td>6.82</td>
</tr>
</tbody>
</table>

\[ V_{\text{app}} = 0.576 \times 10^{-4} \text{ m/s} \]

\[ I = 1.7 \times 10^{-10} \text{ C/s} \]

<table>
<thead>
<tr>
<th>( S )</th>
<th>( V_{\text{app}} )</th>
<th>( V_{\text{app}} )</th>
<th>( 2V_{\text{app}} - V_{\text{app}} )</th>
<th>( Q_{\text{calcd}} )</th>
<th>( Q_{\text{calcd}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>8.326</td>
<td>8.326</td>
<td>8.326</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>1.33</td>
<td>8.826</td>
<td>8.826</td>
<td>8.826</td>
<td>11.9</td>
<td>11.9</td>
</tr>
<tr>
<td>1</td>
<td>8.326</td>
<td>8.326</td>
<td>8.326</td>
<td>10.5</td>
<td>10.5</td>
</tr>
<tr>
<td>3.33</td>
<td>8.826</td>
<td>8.826</td>
<td>8.826</td>
<td>9.0</td>
<td>9.0</td>
</tr>
<tr>
<td>10</td>
<td>10.326</td>
<td>10.326</td>
<td>10.326</td>
<td>8.9</td>
<td>8.9</td>
</tr>
<tr>
<td>31.6</td>
<td>10.826</td>
<td>10.826</td>
<td>10.826</td>
<td>8.7</td>
<td>8.7</td>
</tr>
<tr>
<td>100</td>
<td>11.326</td>
<td>11.326</td>
<td>11.326</td>
<td>11.8</td>
<td>11.8</td>
</tr>
<tr>
<td>316</td>
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<td>11.826</td>
<td>11.826</td>
<td>11.1</td>
<td>11.1</td>
</tr>
<tr>
<td>1000</td>
<td>12.326</td>
<td>12.326</td>
<td>12.326</td>
<td>11.0</td>
<td>11.0</td>
</tr>
</tbody>
</table>

\( I \text{ Trans} = 10^{-9} \times \text{ Trans} = 10^{-9} \times 3 \times 10^{-3} \times 10^{-1} = 3 \times 10^{-12} \times 3 \times 10^{-1} = 9 \times 10^{-13} \)

\( Q_{\text{trans}} = 10^{-9} \times 3 \times 10^{-3} \times 10^{-1} = 3 \times 10^{-13} \times 3 \times 10^{-1} = 9 \times 10^{-13} \)
May 5, 1958.

Transistor Transistors - infinite base resistance.

Transistor oscillator - schematic

For small $I_e$, $I_e = \text{current} \approx \text{transit time} \times \text{speed of}

Assuming uniform field, $Transit = \frac{W}{V}$

Speed = \frac{V}{Transit}

May 7-58

Possible HF Transistors.

Problem in HF oscillator transistor is to make

base lead contacts. We know how to make thin

layers, e.g. by diffusion, and we can think in

terms of layers a fraction of a micron thick, with

transit times of the order of 10^-6 sec. However,

to make good transistors one has thin base

layers, the lateral dimension of which, 4 or 5, should be only 10 or the base width.
We might avoid these problems by thinking of 1) circuits not requiring external base leads, biased by an avalanche at the collector. The avalanche current (current) need be only \( \frac{1}{4} \) of the average collector current. Base heating could then be done by collector current sources, without serious degradation of performance, i.e., since the avalanche current flowing during the peak of the collector cycle need be only a small fraction of the total current.

2. Transistor base diodes
   a. Minority carrier diffusion delay diode
   b. Avalanche delay diode

3. Another negative resistance diode is the following:

   Assume a structure as follows:

   ![Diagram](attachment:image.png)

   This structure has a negative resistance by virtue of the following arguments. At low voltages across the collector junction, a small current of holes flows into the base. By virtue of avalanche, but there also flows out to the top photoconductive, without disturbing the...
High under the emitter high enough that field.

Holes flow out of the emitter across the base.

At higher voltages, the holes injected into the base will create an IR drop in the layer under the emitter, forward biasing the emitter, causing current to flow. These electrons after crossing the base, cause avalanche to more holes to flow into this region of the base. This high current condition can then be maintained at lower slander collector voltages. Thus the IV characteristic looks like this:

\[\begin{align*}
V_e & \rightarrow \\
I & \rightarrow \\
\end{align*}\]

Ratio of \( V_o \) to \( V_h \) has as high as 2:1 have obtained on our standard Transistor, de-biasing emitter and have leads.

The photo at right is an IV plot of our NPN Transistor Emitters shorted to base.
Since separate emitter and base connections are no longer needed for this device, the effective base-emitter dimension could be substantially reduced. Oscillator using this device:

Key point should be about \( I_{MAX} \) which one should be able to get up above 1000 nA.

For \( V_{BC} = 2.5 \) V, \( I_e = 10 \) mA, \( B = 100 \), \( F_{max} = 1000 \) Hz, \( W_{peak} = 1 \) µW.

\[
\begin{align*}
V_{BC} &= 2.5 \\
I_e &= \frac{2.5}{100} = 0.025 \\
F &= \frac{10^{-6}}{1000} = 10^{-9}
\end{align*}
\]

\[
T_{trans} = \frac{10^{-6}}{10} = 10^{-7} \text{ sec}
\]

Read and understood:
Jean A. Hoern
May 19, 1953

Difficulties with N-T Read's negative resistance device is that the avalanche does not depend solely on the instantaneous field — but rather the avalanche process occurs as a result of a certain micro - planner, extending a finite time after the application of a high field.

It may be possible to achieve negative resistance without extending to this. However, if the current that can be made to extend over a longer portion of the cycle.

Consider the following: An N-P-N structure, with total number of impurities small enough in the p-region that punch through can occur.

\[
\begin{align*}
\text{Equilibrium} \\
\end{align*}
\]

A bias is applied to collector, so the region suddenly into the base, with a net decrease in the positive change in the base, either by injection of electrons or by driving out holes. By proper doping ratios, one should be able to make this primarily hole current. Then, as punch-through occurs, electrons are allowed to flow into the base. The number of electrons
in the base building up as long as the voltage is above punch-through voltage. This number is limited by space charge limitations. If these electrons flow to the collector under a high field and remain in a high field region even as the collector voltage drops.

Thus, it may be possible to make a negative resistance device in which the negative resistance holds up for quite reasonable voltage swings on the collector — this may be a good one to look for.

May 14

The technique proposed on 35-36 might be useful in the case of the NPN transistor as well as for an NPN or PNP. The alpha of the transistor is effectively made very large for low currents — this switching current is then increased and actually is controlled then by the geometry of the emitter and base.
regions. This then is a way to design for switching currents. It also makes the device faster, since the effects of the minority groups another way for the stored later to get out of the base.

Two terminal:

Three terminal:

In the above 3 terminal, the npn should be the high x transistor.

This also has the advantage of making the switching voltages of the transistor more stable: for low sec. current it is quicker but also has the “spike” or the “alpha” of one of the transistors (the npn usually) goes high.

Discussed this with J.A. Haenni & C.E. Moore.

Jan A. Haenn

[Signature]

5-12-18

May 14, 58
PM PD - Conductivity modulated.

Let us consider the following structure:

\[ \begin{array}{c}
\text{PM} & \text{PD} \\
\text{N} & \text{N} \\
\end{array} \]

Here we assume that the diffusion length of electrons injected across \( \text{In} \) is much smaller than the base width \( W \).

As current is forced through this junction, it is made up of electrons at the junctions and \( \text{In} \) holes far from the junction - Considering only the base \( W \) for the time being, let us determine how much of the current is made up of electrons at \( \text{In} \). Consider first an infinite bulk.

\[ J_n + J_p = J_{\text{total}} \]

Conditions:

\[ J_n = \frac{N_p}{\mu_n (\frac{E_n}{kT} - \text{grad} n + \text{En})} \]
\[ J_p = \frac{N_n}{\mu_p (\frac{E_p}{kT} - \text{grad} n + \text{Ep})} \]
\[ \rho = N_p + N_n \quad \text{(electron-hole neutrality)} \]
\[ \text{div} \, J_n = \frac{\rho}{\tau} \quad \text{(constant lifetime)} \]

With boundary condition:

\[ J_p = 0 \text{ at } x = 0 \]

Solve for \( J_n \) vs \( x \).
Known Equations:
\[ J_n = J_r - J_p \]
\[ = J_r - \left[ \mu_p \left( \frac{\partial E}{\partial r} + p \right) \right] \]

But \( \frac{\partial E}{\partial r} = \frac{\partial q}{\partial r} \)
\[ p = \frac{n}{n} + \frac{n}{n} \]

\[ J_n = J_r - \mu_p \left[ \frac{\partial q}{\partial r} + (n\pi n) \right] \]

Else \[ J_n = \mu_p \left[ \frac{\partial q}{\partial r} + n \right] \]

Solve for E:
\[ E = \frac{1}{\mu_p} \left[ J_r - J_n - \mu_p \left( \frac{\partial q}{\partial r} + (n\pi n) \right) \right] \left( \frac{1}{n} \right) \]

Substitute:
\[ J_n = -\frac{\partial q}{\partial r} + \mu_p \left( \frac{n}{n} \pi n \right) \left[ J_r - J_n - \frac{\partial q}{\partial r} \right] \]

\[ J_n \left[ 1 + \frac{n}{\mu_p} \frac{n}{n} + n \right] = -\frac{\partial q}{\partial r} \left( \frac{n\pi n}{n} \right) + \frac{n}{\mu_p} \frac{n}{n} J_r \]
Transit Time Effects

Effect of $R_0$, $C_T$

$$J = J_{P,52} + J_{D,52}$$

**Extra effects to consider:**

1. Series base + emitter resistance.
2. Currents through base, carried by majority carriers.
3. Transition capacitors (primarily emitter).
4. Injection at emitter at high frequencies.
5. Diffusion delay through two of the regions.

Comment: the small compared to $1/WC_e$

Our structure: $L_{Be} \approx 10^{-3}$, $W_{Be} \approx 10^4 \times 10^{10} \approx 10^{14}$, so we can't make it.

We must reduce $L_{Be}$.

Another way of thinking of the device:

As collector bias is changed, in $P$-base, holes are drawn from collector up through region to emitter regions, allowing electrons to come in from emitter. Holes go to the change, then drift to collector, leaving holes.
<table>
<thead>
<tr>
<th>Voltage</th>
<th>Fw</th>
<th>Bf</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.4</td>
<td>4.0</td>
</tr>
<tr>
<td>100</td>
<td>1.8</td>
<td>5.3</td>
</tr>
<tr>
<td>150 (1mA)</td>
<td>3.1</td>
<td>8.5</td>
</tr>
<tr>
<td>(2mA)</td>
<td>3.3</td>
<td>8.3</td>
</tr>
<tr>
<td>(5mA)</td>
<td>2.6</td>
<td>6.7</td>
</tr>
<tr>
<td>2</td>
<td>2.0</td>
<td>8.8</td>
</tr>
<tr>
<td>2mA</td>
<td>1.7</td>
<td>10</td>
</tr>
<tr>
<td>1mA</td>
<td>1.8</td>
<td>9.6</td>
</tr>
<tr>
<td>300</td>
<td>2.8</td>
<td>13.7</td>
</tr>
<tr>
<td>350</td>
<td>6.0</td>
<td>20</td>
</tr>
<tr>
<td>300</td>
<td>13.6</td>
<td>36.41</td>
</tr>
</tbody>
</table>

Diode Transistor

V = 5 V
I = 1 mA

stub

150

9.3
Intrinsic Barrier Transistor design:

Question: Advantage of thin structure for having better intrinsic regions.

Design I  Collector Thickness = 5 µ
Design II Collector Thickness = 30 µ

Bare: Collector

\[ C_0 = 5 \times 10^{18} \]
\[ l_0 = 0.9 \, \mu \]

\[ C_0 = 10^{20} \]
\[ l_0 = \frac{5}{2} = 2.5 \, \mu \]

\[ C_0 = 10^{20} \]
\[ l_0 = \frac{5}{72} = 0.695 \, \mu \]
\[ l_d = \frac{5}{2} \, \mu = 4.17 \, \mu \]
Bunch through drive.

For this structure:

The I-V characteristic will be:

If the density in the center is skewed:

The I-V characteristic will be skewed.

Such diodes could be used for function tables, since each one will be independent of every other one, so many of them could be put on a single wafer.

Method of fabrication:

1. Oxide wafer
2. Etch boron oxide
3. Etch silicon to thickness (optional)
4. Diffuse phosphorus and arsenic
5. Evaporate contact material
July 3.

C. S. Lokenst has observed that under some conditions, at least, the aluminium tends to separate at the water-air interface. Electrically, the contacts are not well separated, but by shaking about 10 seconds in 30 HNO₃ : 1 HF, they may be separated, without increasing the sheet resistance of the aluminium alloyed layer.

<table>
<thead>
<tr>
<th>After 1st Etch (5 sec, 20%)</th>
<th>After 2nd Etch Same</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current at 0.5 V (mA)</td>
<td>Current at 0.5 V</td>
</tr>
<tr>
<td></td>
<td>Current at 2 V</td>
</tr>
<tr>
<td></td>
<td>Amps</td>
</tr>
<tr>
<td>+1</td>
<td>&lt; 0.005</td>
</tr>
<tr>
<td>+2</td>
<td>&lt; 0.005</td>
</tr>
<tr>
<td>Etc.</td>
<td>&lt; 0.005</td>
</tr>
<tr>
<td>1</td>
<td>&lt; 0.005</td>
</tr>
<tr>
<td>0.05</td>
<td>&lt; 0.005</td>
</tr>
<tr>
<td>1</td>
<td>&lt; 0.005</td>
</tr>
<tr>
<td>1.5</td>
<td>&gt; 0.02</td>
</tr>
<tr>
<td>2</td>
<td>&gt; 0.02</td>
</tr>
<tr>
<td>2.2</td>
<td>&gt; 0.02</td>
</tr>
<tr>
<td>2.5</td>
<td>&gt; 0.02</td>
</tr>
<tr>
<td>3</td>
<td>&gt; 0.02</td>
</tr>
<tr>
<td>3.5</td>
<td>&gt; 0.02</td>
</tr>
<tr>
<td>4</td>
<td>&gt; 0.02</td>
</tr>
<tr>
<td>4.5</td>
<td>&gt; 0.02</td>
</tr>
<tr>
<td>5</td>
<td>&gt; 0.02</td>
</tr>
<tr>
<td>5.5</td>
<td>&gt; 0.02</td>
</tr>
<tr>
<td>6</td>
<td>&gt; 0.02</td>
</tr>
<tr>
<td>6.5</td>
<td>&gt; 0.02</td>
</tr>
<tr>
<td>7</td>
<td>&gt; 0.02</td>
</tr>
</tbody>
</table>
This data shows that about half of the emitter-base junctions have cleaned up sufficiently to be usable. This has been done with no sacrifice in the equivalent resistance. In fact, the forward base-impedance shows a significant improvement over their new coming off the line of about 10 Ω, these being about 35 Ω.

The photograph at right shows the separation between emitter on left and base on right. Separation is about 10 μ.

500x

A finer grain structure on the base is desirable if very small structures are to be made. Emitter is fine-grained enough.
July 15, 1958.

Parametric Amplifier Diode.

The figure of merit of the diode for parametric amplification is the crossover frequency, i.e., the frequency at which $X_e = R_e$ (series resistance).

In general, the capacitance varies as $1/p$ and the series resistance varies as $1/p$, the resistivity as long as the mobility is constant. Therefore, the RC time constant $\tau$ varies as $1/p$. This means that the time constant should be reduced by going to higher and higher doping density.

In doing so, the total impedance of the diode decreases, making the unit inconvenient for use. It would be more desirable either to

1. cut back to impedance is 0.50 at operating frequency, say 10 MHz.

2. Series a number of units to increase impedance level.

In order to cut impedance levels, we suggest making a linear structure rather than an area structure, i.e., use the capacitance between two surface-diffused areas, one $n$ and one $p$. In this way, contacts
can be made extremely close to the junction, and the capacitance per unit area will be quite high.

As an example, let us look at the following structure: using 50 cm p type material, different phosphorus at $10^{21}$ for i.e., p-doped phosphorus layer + different Boron $10^{17}$ cm. We can estimate the capacitance per unit length of this structure:

![Graph showing concentration and distance from surface]

- Concentration:

![Graph showing gradient and capacitance]

- Capacitance:

![Graph showing capacitance with units]
Capacitance will be about 100 \text{ mF/cm}

- \frac{5 \times 10^{-5} \text{ mF/cm}}{\text{cm}^2} \times 10^{-4} \text{ cm} = 100 \text{ mF/cm}

\text{Total (make small dot) (0.0 cm long)}

Capacitance to 50 cm material

\begin{align*}
C_B &= 2.5 \times 10^{-6} \\
\frac{\partial C}{\partial t} &= 4 \times 10^{-4} \\
9.2 \text{ LD.} \\
\frac{\partial C}{\partial t} &= 2 \times 10^{-25} \times 10^{-2} \\
&= 2 \times 10^{-9}
\end{align*}

\begin{align*}
C &= 5 \times 10^{-5} \text{ km}^2 \\
A &= 10^{-4} \text{ cm}^2 \\
\sigma &= 1 \text{ mF}^{-1}
\end{align*}

Small dot.

15 mld. perimeter, 1 mid dot contacts.

\frac{1}{5} \text{ square. 7102.89 - under.}
PnP Diodes

0.1 ncm N → 5 \times 10^{18}

C_0 = 10^{-22} \hspace{1cm} 2 \times 10^{20}

L_D = \frac{7 \mu}{m} = 5 \mu

Gradient at 1 cm 6600 \pm 10.

\frac{dc}{dx} = 10^{-2} \hspace{1cm} \frac{C_0}{d} = \frac{2 \times 10^{20} \times 10^{-2}}{2 \times 10^{-2}} = 5 \times 10^{18}

C = 0.001 \hspace{1cm} 4 \times 10^4 \text{ pF cm}^{-2}

\text{For } 10^{-3} \text{ cm}^2 \hspace{1cm} C = 10 \text{ pF}

L = \frac{1}{2}

L_C = 0.02 \times 40 \times 10^{-12} = 10^{-12}

\text{f max. } = \frac{1.6 \times 10^{12}}{160 \times 10^{11}} \text{ cycles}

= 100 \text{ kHz}.
Parametric Amplifier Diode Configurations.

In order to get small effective area:

Symmetrical Structure:

1. Oxide.
2. Plate Shield.
3. Diff n⁺
4. Reverse Supply.
5. Diffuse p⁺
6. Diode.

Package:

Skin depth: \( S = \left( \frac{\zeta \mu_0}{\delta} \right)^{\frac{1}{3}} \)

\( \mu = 10 \pi \times 10^{-8} \)

\( \zeta \) yield: 0.08 \( \frac{\text{a}}{\text{b}} \)

1 KMC: 8002 cm²

1 in skin depth 1 mil width 3 x 10⁻⁵ dec.; 3 x 10⁻³ cm.; 3 in. long

10 mils 0.2 in.

Inductance:

1 in S difficulty 50 kH.

\( L = 0.00508 \left( \frac{\lambda + \frac{4\pi}{\delta} - 1}{\text{cm}} \right) \) \( \mu \text{H} \).
Dop - Dop model.

1. 50 cm P-type.

July 28. Resistance through graded dope

1. become gradient 2
2. mobility const.

\[ \int R(x) = \int \frac{1}{\sigma(x) x} \, dx \]

\[ R = \frac{1}{\sigma(x) x} \]

Time exponential

\[ R = R_0 e^{-ax} \]

2. \( R = 10 \mu \text{ohm cm} \)

Linear: \( 10 \mu \) thin const. \( k = 10^{-3} \)

<table>
<thead>
<tr>
<th>C</th>
<th>V</th>
<th>( \times 10^5 )</th>
<th>N edge</th>
<th>PoP</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 V</td>
<td>4</td>
<td>7.65 x 10^{-6}</td>
<td>2 x 10^{-7}</td>
<td>.12</td>
</tr>
<tr>
<td>12 V</td>
<td>2</td>
<td>1.2 x 10^{-5}</td>
<td>6 x 10^{-7}</td>
<td>.07</td>
</tr>
<tr>
<td>15 V</td>
<td>1.6</td>
<td>.8 x 10^{-5}</td>
<td>8 x 10^{-7}</td>
<td>.06</td>
</tr>
<tr>
<td>25 V</td>
<td>10</td>
<td>2.0 x 10^{-5}</td>
<td>10 x 10^{-8}</td>
<td>.04</td>
</tr>
</tbody>
</table>
for 1 µµµ at gradient 0/10^25, 1 V,  
\[ A = 10^{-5} \text{ cm}^2 \]

radius = \( 3 \times 10^{-3} \approx 0.01 \)"

Series L allowable for 160 cm = 1 µµµ

Pedestal mount:

Area of contact for 1 µµµ:

\[ C = \frac{yA}{y} = \frac{25 \times 10^{-12} \times 1.09 (\text{cm}^2)}{1.09 (\text{cm}^2)} \text{ µµµ} \]

At 0.02 um m

\[ d = 0.01 \text{ um} \]

Use 111 xtol. kelly dot: 

At 56 perhaps.

110 direction lens

100 4 sided pipe.
Another possibility is the case of grain boundary for small area high gradient.

[Diagram of grain boundary and another boundary labeled as 'differed.']
High Efficiency Photovoltaic Cell

Maximum theoretical efficiency of a photovoltaic cell is obtained when the wavelength of the incident radiation is just on the edge of the intrinsic absorption of the semiconductor. At best only the band-gap energy can be used of the energy of the incident photon.

For a single semiconductor material P-N junction the efficiency is limited by:

1. No absorption to produce hole-electron pairs from long-wavelength incident radiation.

2. Inefficient use of short wavelength radiation.

In principle, a higher efficiency converter could be made by utilizing stacks of P-N junctions of differing band gaps stacked in such a way that each uses the high energy photons to create pairs in a high gap material, then the lower energy photons, etc.
Schematically this is as follows:

\[ h\nu \rightarrow \begin{array}{c} \text{PN} \\ \text{Eq}_1 \end{array} \begin{array}{c} \text{PN} \\ \text{Eq}_2 \end{array} \begin{array}{c} \text{PN} \\ \text{Eq}_3 \end{array} \quad \text{Eq}_1 > \text{Eq}_2 > \text{Eq}_3 \quad \text{etc.} \]

Then, since every detector converter is working on a much smaller band of energies closer to theoretical efficiencies, could be obtained. This may not be practical as long as cells are expensive to fabricate, and materials are expensive. However, if this principle can be used in a single junction detector, or in a multiple junction detector or in a single slab, it may be practical.

One way in which this could be effected in practice would be to grade the energy gap across the single PN junction. In this case, if light is incident from the high gap side, the photons will be absorbed at the energy gap energy. Thus they have no escape energy to be lost to lattice vibrations.
Such a cell will respond both to radiation absorbed on the high gap side and the low gap side of the junction. We can show that it will use the high energy radiation more efficiently than the low gap homogenous junction.

\begin{center}
\begin{tikzpicture}
\draw[thick] (0,0) -- (1,0) -- (1,1) -- (0,1) -- cycle;
\draw[thick,->] (0.5,0) -- (0.5,0.5);
\end{tikzpicture}
\end{center}

Ceramic Box (Annealed)

1300°

50:50 Silicon - &Z&2O+

Highly pure Aluminum

Hydrogen

very dry

2059

2036
Probabilty of FDD Diode Converter for low loss.

Advantages:
1. Higher impedance for a given area.
2. Higher Q.

Question: Figure of merit for Diode Converter.
A. Energy loss/cycle.
B. Amount of nonlinearity.

\[ M = \frac{\text{Energy converted/cycle}}{\text{Energy loss/cycle}} \]
Exp Run for 3 Hrs. 7 Volts.

Tame Cat

<table>
<thead>
<tr>
<th>Beas</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.7</td>
</tr>
<tr>
<td>1</td>
<td>3.1</td>
</tr>
<tr>
<td>2</td>
<td>5.0</td>
</tr>
<tr>
<td>3</td>
<td>2.0</td>
</tr>
<tr>
<td>5</td>
<td>1.68</td>
</tr>
<tr>
<td>7</td>
<td>1.25</td>
</tr>
<tr>
<td>10</td>
<td>0.93</td>
</tr>
<tr>
<td>15</td>
<td>0.88</td>
</tr>
<tr>
<td>20</td>
<td>0.84</td>
</tr>
<tr>
<td>30</td>
<td>0.82</td>
</tr>
</tbody>
</table>

It is the object of this invention to provide a semiconductor device in which the spatial position of the conduction path from one surface to the other may be controlled by the application of proper positioning voltages applied to deflection electrodes. This device could then serve in many of the same applications in which an electron beam device is used, such as display, camera tubes, beam switching, amplifiers of the traveling wave variety, etc. For these applications, this beam positioning device might be used in conjunction with photodetectors, electro-luminescent materials.

To see how the beam forming part of the device works, let us consider the terminal characteristics of an n-p-n transistor.
With the base voltage fixed, and with the collector bias, over a portion of its characteristic, a negative resistance. However, as the base is biased farther in the negative zone (base-emitter junction, reverse biased), more collector voltage is required for the same current flow. Thus, if there is a potential gradient in the base layer, the current will tend to flow in the region where the base is biased the least in the reverse direction. Thus, by varying the potential of the base layer, and its spatial variation, the position of the current path through the structure can be varied. Furthermore, if the base is reverse biased at the edges, forward biased at one point by avalanche current flowing out through the base, the current path will be limited to a very small area.

Jan 14, 1957

This essential to this type of operation, that there be a regenerative mechanism for the current flow, so that even though the potential applied to the central electrode are in the sense to drive the current off, it will continue to flow through the device. The avalanche
multiplication which causes the negative resistance region illustrated above has the property that another structure which may be more favorable is the PNPP structure. In this case, the I-V characteristics here are similar, but the voltage across the device in the high current state are smaller.

Again, the device does not conduct an actuality of the base as reverse biased.

The device shown is made in the following way: We use the pnp pnp as an example:

If a current I is forced through the device, and the terminals on the N, layer are reverse biased with respect to the P layer. The current path will be confined to a reverse region in the middle of the device, its position.
Being centered when the voltages are equal, and moving to the left as the voltage on the right hand terminal is increased (more negative bias). Thus, the position of the current path can be changed by applying differing voltages between the contact on the H-layer.

It is apparent that the same thing can be done with more than two contacts on the H-layer, giving a two-dimensional positioning of the current path:

Since only the negative resistance characteristic is required, the same thing can be done with only an nnp structure or a pnp structure. In silicon, the nnp structure is preferable, since the differences in the voltage where current starts to flow, and that at which the current is sustained is greater than in the case of the pnp structure.

In the pnpnp structure, the device is symmetrical from the two sides, with...
a change in polarity, thus, deflection terminates could be made on the middle 11 layer for, say, the X positioning of the beam, and on the middle 9-layer for y positioning of the beam. This method has an advantage in that the x- and y-position of the beam is more nearly a linear function of the deflection voltage than in the case where four deflection terminals are made to the same layers.

In the above, we have reviewed the technique for defining the current path between two sides of a structure to a small spot and as positioning this spot in any position by application of suitable potentials to the deflection plates. Now we shall examine some possible applications for such a device.

1. Image pick-up device. If we take the above described beam positioning device, either in the three-layer or four-layer variety, in combination with a photo-conductive film, the combination can be used to read the conductivity of the film as a function of position. This is a useful...
A marker scan is applied to the deflection plates terminals. A signal may be extracted from the device, either a voltage signal by using a constant current through it, or vice versa. In this case, the device would be as follows:

![Diagram of a device with a scanner, photodetector, and signal output]

Any number of photodetectors might be used. The use of the semiconductor body comprising the first layer of the scanning device is one possibility. The device is readily cooled for greater photosensitivity.

3. As an image forming or display device. In combination with some light emitting material the above device can be used to display an image or another type of information. There are several possibilities for the light emitting substances:

a. Electroluminescent materials. The above device provides a low impedance path from the surface to the others in one chosen
Spot; elsewhere a high impedance. Thus, if
inserted in the arrangement below, light will be
emitted in the chosen spot, not elsewhere.

5. Some semiconductor materials emit light
in the middle region with the passage of DC
current, which eliminates the capacity problem
involved in AC. For instance, if a silicon PN
junction has appreciable current flowing in reverse
bias, visible light is emitted at the junction.

Silicon absorbs visible radiation strongly, so
the junction must be at or very near the
surface if the light is to be seen. Semiconductor
materials with wider band gaps, corresponding
to energies greater than that of a photon of
visible light, will be transparent to visible
light, and so may be more effective in this application. Silicon carbide is one example in
which visible light has been observed easily.
In the case of an extra PN junction, reverse biased
in the breakdown region could be used, resulting
in a PMVP structure.

Light from a gas discharge, or breakdown of an
insulator might be used.

Jan 15, 1967

5 3. A switching device. If several contacts
are made to one side of both sides of the device,
connections may be made between a selected
pair by applying proper positioning potentials.

Since the position of the beam is a
function of two switchable, the deflection
voltages; certain logic functions may be
performed by proper electrode configuration.
As an example: the function \( A \lor B \), but not
\( A \land B \) would be given by an electrode configura-
tion of 4 contact regions on the back, connected
diagonally, with the signals \( A \) and \( B \) applied
to the deflection plates.

\[ \begin{align*}
E & \text{a} \\
A & \text{b} \\
A & \text{c} \\
A & \text{d} \\
\text{a} & \text{b} \\
\text{a} & \text{c} \\
\text{a} & \text{d} \\
\text{b} & \text{c} \\
\text{b} & \text{d} \\
\text{c} & \text{d} \\
\text{a} & \text{b} \lor \text{a} & \text{c} \\
\text{a} & \text{b} \lor \text{a} & \text{d} \\
\text{a} & \text{c} \lor \text{a} & \text{d} \\
\text{b} & \text{c} \lor \text{b} & \text{d} \\
\text{c} & \text{d} \lor \text{a} & \text{b} \\
\text{c} & \text{d} \lor \text{a} & \text{c} \\
\text{c} & \text{d} \lor \text{a} & \text{d} \\
\text{d} & \text{c} \lor \text{b} & \text{d} \\
\text{d} & \text{c} \lor \text{b} & \text{d} \\
\text{d} & \text{d} \lor \text{a} & \text{b} \\
\text{d} & \text{d} \lor \text{a} & \text{c} \\
\text{d} & \text{d} \lor \text{a} & \text{d} \\
\text{d} & \text{d} \lor \text{b} & \text{c} \\
\text{d} & \text{d} \lor \text{b} & \text{d} \\
\text{d} & \text{d} \lor \text{c} & \text{d} \\
\end{align*} \]
This type of logic element can be carried much further by multiple connections to deflect electrode, and multiple contacts on both front and back surfaces. It would appear that the resulting output voltages are suitable for direct coupling, so many of these elements are possible on one wafer.

January 23 59

Methods of interlocking multiple devices:
In many applications now it would be desirable to make multiple devices on a single piece of silicon in order to be able to make interconnections between devices as part of the manufacturing process, and thus reduce size, weight, etc. as well as cost per active element. Several considerations enter here: First, the blocks of devices which make up one unit should be large enough that the number of external leads is substantially reduced, realizing an economic advantage in fabrication costs. Secondly, either
The number of elements must be small, or the yield very high in order that overall yield is high enough to be economical. Some steps may be taken here in transistor and logical design in order to make ample high yield elements. Still, some compromises must undoubtedly be made. Third, the method of making interconnections should fall naturally into the pattern of making the elements. Fourth, some method of duplex protection must be utilized.

The following seems to meet most of these requirements: Suppose we want to make a diode matrix for a full adder.

```
A A
A A
A A
A A
A A
```

```
We start with, say high resistivity n-type or i material. Then, after oxidizing a
P-type impurity is diffused through holes in
the oxide, diffusing all the way through the
wafer

\[ \text{Oxide} \]

Then, after removing oxide on the top, an n-type
impurity is diffused in:

\[ \text{Metal connections are made through the holes by evaporating metal} \]
in the oxide, to interconnect the dikes as desired
for a particular circuit.

Contacts might be made by either making
two connections to one diffused island, or by
coating the oxide with resistive material,
and making connections to it.

The important features of the above are
1. Isolating multiple units by including
   at least 1 p-n junction between them. More
   common will be the case where 2 junctions
   are included between the elements, such
   that one is always reverse-biased, regardless
of the polarity of the voltage between the elements.

2. Use of the silicon layer as an insulator to isolate contact strips from the underlying silicon.

3. Protection of junctions at the surface with an oxide layer.

The above is applicable to transistors as well as diodes.

A generalized logic element might be the following:

Direct coupled transistor adder:

\[
\begin{align*}
S &= A \cdot B \cdot C \\
S &= A \cdot B \cdot C \\
S &= A \cdot B \cdot C \\
S &= A \cdot B \cdot C \\
L &= A \cdot B \cdot C \\
L &= A \cdot B \cdot C \\
L &= A \cdot B \cdot C \\
L &= A \cdot B \cdot C \\
E &= A \\
A &= B \\
\end{align*}
\]
Full adder using beam switching device:

One Beam device

1. Pulls beam
2. Pushes

No carry for ABC
This looks OK

Equivalent from npn's (could be npn's) (avalanche)
October 18, 1961

Today Gordon E. Moore discussed with me the possibility of building a device to serve as a variable gain element in an adaptive system which the resistance of a semiconductor element could be changed by the diffusion under a field of a light impurity, or a fast-moving impurity e.g. gold, lithium could change the carrier concentration in the element:

\[ \text{Lithium doping contact, } J \text{ effective conductivity type} \]

Thus the conductivity from A to B would depend on the integral of lithium current from C into the bar, which would be controlled electrically by diffusion in the lithium at rapid enough.

[Dale]
January 30, 1969

Last week Gordon, Ed and I were discussing another method of device isolation which seems to have advantages.
The disadvantage of isolation with P-N junctions is the extra capacitance across the P-N junction which causes extra noise.

Recently it has been possible to bond glass directly to silicon using temperatures just above the softening point of glass. This can be done with metallized wafers as well. After bonding to completed wafers & integrated circuits, it is possible to strip away the silicon to leave isolated regions of silicon containing the active devices. This would substantially reduce the capacitance compared to PN junction isolation.

The steps of the proposed process are shown on the next page.
1. Silicon Wafer
   Backside
   Stick holes
   Diffuse Light
   Make XH Lines
   Diffuse Light
   Metal holes
   Metal Grooves on Si
   Form contacts for contacts
   Metal Grooves on Si
   Stick glass over silicon
   Wash back side
   Stick away silicon to isolate

   Leads could be attacked by further etching through the SiO2 films and contacting metal film from the bottom.

   R.H. Jiinger  June 30, 1962

   Read unilaterally 12/12/62. I also remember drawing this with MMN early this year.
Dave Helckher has developed a constant current source of accuracy of the order of 0.1%. Such devices, or any constant current source, could be applied as a digital voltmeter by measuring time ratios. The measurement could be done digitally. A highly accurate clock frequency would be required, but only stability of frequency over the count period, which could be a fraction of a second.

\[ \text{Diagram:} \]

The ratio of counts in counter 1 and counter 2 would give the ratio \( \frac{I_1}{I_2} \) of current if a gating element is arranged to leave the switch closed for one cycle.

\[ \text{Clock + counter} \]

... would be made useful for multi-element installations. These ideas,
but with frequency fluctuations on the clock
have been submitted yesterday by S. Schwartz.
His application is subject to frequency corrections.
For the DVM, no such stability is needed.
October 17, 1962. — Adaptive Machines.

In examining methods that might be employed to use the insulated-gate field effect device, I have been looking at the basic limitations, from a practical point of view, of the adaptive system. Ridgesway, and others have shown that the “adaptive” system does provide optimum convergence, and generally other properties. To realize this system, a large number of “weights” must be used, if the system is to have any potentiality, at all. In the systems built thus far, the total number of weights used has been limited to of the order of 100, resulting in an adaptive system of very little capability compared to what is desired.

The use of the insulated gate FET (Fank-Warren) as the analog weight certainly is possible. However, the hope is that this device can be made in large numbers on a common substrate, with the interconnection wiring, including the
Vicini for "adapt" commands. The total number of elements for a system of great capability will, however be very large, and the amount of inter-connection wiring will be very large.

Realizing this limitation, one may set these criteria:
1. The total memory must be very large.
2. The memory can be adapted; i.e., changed by the new experience - training.
3. Every memory element participates in every decision made, in the "ideal" system.

Because of the enormity of the memory, the present system, which connects through the memory, has an enormous amount of wiring. This is probably the first limitation.

In trying to solve this basic limitation, I have thought about coincident current memories, or other matrix schemes, using other than magnetic storage. However, the fact that every element participates in the decision (3 above) makes the
less attractive, since the whole mercury must be interno gated, which takes time, and a lot of switching circuit would be required.

The variant which I have found is to use a system which scans the input data, weighting each input sample appropriately. Then the system uses a serial input rather than a parallel one, the memory can be serially read out in synchronism with the input data.

In comparison, the serial + parallel systems would be schematically shown as follows, for a 1 neuron system.

[Diagram of a neural network system with labels and connections, including input data, memory, adapt control, and other components.]

Parallel input (all memory read at once)
Serial input (serial memory)

The total amount of input data which we would like to handle is large, much more than indicated. Consequently, the difference in amount of wiring, i.e., number of connections is much more than indicated.

A new look at the possible embodiments of the various elements of the serial system.

Input: If we were doing character recognition, we might simply optically or electronically scan the character, using a television-type raster. This
then gives the input function $f(t)$. Some logical, rather than adaptive, system might be used to preprocess this information—i.e., to get standard size, or contract.

If the input were to be sound, for speech recognition, this could be used directly, or perhaps frequency distribution vs. time could be used. Again, standardization of the sound level, for example, might be desirable.

Variable gain element: This is an analogue multiplier, which might be simply an amplifier with a fixed or automatic gain control circuit, with the equivalent of the ABC voltage coming from the memory.

Memory: This memory must be able then to produce a voltage in time to control the ABC unit. It is read out in time in synchronism with input scene. With these requirements, a simple tape loop or drum for magnetic recording and playback
Could be used, with its large interest capacity! During training, a magnetic memory seems most desirable; however, after training, it could be replaced with a fixed memory, such as a photographic plate, which is scanned optically, or with TV techniques.

The memory: a simple integrator, which can be an operational amplifier with capacitor in feedback loop. After completing the cycle, the output is read, reset to zero.

Adapt system: This system turns out to be very simple... a multiple of the input signal must be added to the memory. This multiple is proportional to the (actual output minus desired output). For the memory this is the equivalent of recording sound in sound, a standard technique.

Dec 11, 1962

Page 50-55 read - understood Dec 12, 1962. I remember discussing the idea with K.S.N. after an annual Thanksgiving dinner meeting on 10/19/62.
October 19, 1967

I have discussed the system described on p. 80-85 with Gordon Moore at the lab, and have been studying the problem of convergence if continuous input is used, rather than the discrete input studied by Reddy et al.

Certainly, the conditions of linearly separable functions must be applied, as the single-receptor is to distinguish between signals.

It will probably be desirable to standardize the input function. This might be done by setting an initial gain in the input line such that

$$\int_0^t [f(t)]^2 dt = \text{constant}.$$  

In practice the threshold detector on the output will probably be desirable in order that binary decisions are made. Then the information can be handled by logical means thereafter.

For example, let us suppose we want to perform character recognition.
Because we want to distinguish between 500 symbols, numbers, letters, etc. The required number of binary digits would then be 10 since \(2^{10} = 1024\).

Thus we could use one row of the symbol with continuous input, 16 channels in memory, integration, threshold detectors, and binary output.

Studies on simple machines have shown that redundancy of \(n \times 100\) is desirable. 16 bits would be 16 digits. In a decimal matrix about 300, or let us say about 70,000 memory elements, or about 1000 per channel. A 30 x 30 significant bit mean looks simple.

Oct 19, 1962
R. Weaver

Oct 22

Talked to Maurice Oster about the gain element + multiplier, and he suggested that the sample-time sampling might be best. I think this is a good suggestion. Then the memory could be simple on-off as time. To get negative weights. The amplifier could be gated & on/off during
One part of the sample, odd during the
other:

\[ \text{Input} \rightarrow Gated\,\text{amp} \rightarrow \text{Memory} \]

Gated Amplifier:

\[ \text{Input} \rightarrow + \rightarrow \text{P} \rightarrow (\text{Integrator}) \rightarrow \text{Memory} \rightarrow \text{Output} \rightarrow \text{Complement} \]

Reading into the memory would then be
shifting of the edge of + to shift an amount
proportional to \( f_0 \times \text{Input} \times \text{Error} \).

Oct 22, 1962, RH Baye
Oct 13, 1965

Catenary negative tracking — fixed already.

Extension to 2 layer or more metal should be done.

To reduce size of die for IC's the lead bond area should be placed over active chip — better thermal dissipation, more dice/wafer — someone has talked about this before. Plough.

Alternatively more leads — on 2 levels.

HF Power x4:

Base Metal

Shielded face contact HF. x4.

Problems which will appear and need solution:

1. Flexibility to handle many designs.
2. Yield and reliability problems.
3. Automatic flexible testing.
June 6 1946.

Display tube for H F displays.

In a CRT display of high frequency signals, the deflection sensitivity of the CRT tends to be the transit time for the electrons through the deflection plates becomes comparable to the inverse frequency. To a first approximation:

\[ \text{Sensitivity} \approx \frac{1}{\Delta t} \]

where \( \Delta t \) is the transit time between the plates.

The frequency response can be improved by making \( \Delta t \) the transit time small compared to the inverse frequency required is displayed. This has the undesired effect, however, of reducing the sensitivity so there is no net gain.

One way to avoid this is to make use of multiple deflection plates, such that each has a transit time small compared to \( \Delta t \), incorporating them in a transmission line which has the same phase velocity as the electron beam.
The “traveling wave” CRT. The electron wave structures must be exactly loaded in order to yield a velocity equal to that of the electron beam, and are quite difficult to achieve. None are in wide spread use. The velocity due to the transmission line is fixed by the structure.

One solution to this problem would be to use the electron beam itself to carry the information to the multiple deflection plates. As an example, let us suppose we have an amplitude modulated beam accelerated to the same velocity (potential) as the beam to be deflected, which changes the deflection plates:

![Diagram](image)

Each deflection plate interrupts part of the signal beam, such that a current flows through the discharging resistors,
producing the deflection voltage.

The response time of the individual deflection plates is determined by the R-C time constant of the plate capacity and the discharge reactor. Again, the increase in frequency works to the detriment of actual deflection sensitivity. For example, if the plate capacity is $10^{-12}$ farads, the discharge reactor would have to be 100\(\times\) for a 10-nsec response time. Beam current would have to be \(1\text{ Kamps}\) to get 100V deflection voltage, which is about what is needed. Practical beam currents might be \(1\text{ ma}\) per plate, but even this is probably more than could be achieved.

In order to avoid this problem, some current gain must be provided at the deflection plates themselves. Some possibilities are:

1. Secondary emission. Current gains of 10 \(\times\) 50 could be achieved with metals, and perhaps ten times this with certain...
like $MgO$.

2. Multiplication through ionization in a semiconductor device material, or PN junction. At 30 V/secondary, gains of several hundred could be available at practical beam voltages. ($\sim 10kV$)

3. Bombardment induced conductivity or ionization in high resistivity semiconductors.

In all cases, beam deflection of the signal beam could be used, rather than amplitude modulation.

It is probably desirable to use a balanced arrangement between the two deflection plates, such an arrangement could be as follows:

![Diagram of beam deflection setup]
Gun effect?

Somewhat resistive,

\[ \text{Assume } 30 \text{ V/pair produced} \]

\[ 10 \text{ kV} \rightarrow 300 \text{ pairs} \text{ close} \]

\[ \text{Sweep out time must be } \approx 10^{-9} \text{ sec.} \]

\[ \text{Assuming at limiting velocity } \text{ check of } 10^6 \text{ cm/sec.} \]

Thickness must be \[ 10^{-3} \text{ cm} \]

\[ = 10 \mu \text{m} \]

Might as well use Junction.

Power in Semiconductor

\[ \text{Incident beam: 1 watt.} \]

\[ 100 \text{ mA} \rightarrow 100 \text{ V} \]

\[ 5 \text{ watts} \]

\[ \text{Second any current.} \]

\[ 1 \text{ watt} \rightarrow \frac{1}{5} \]

\[ \text{and we need low Q.} \]
3.7 pt/plate.

\[ \frac{1}{2}'' \times 1'' \]

\[ 216 \text{V} \]

Velocity at 25kV: \( 5 \times 10^8 \) cm/sec \( \approx 3 \times 10^5 \) cm/sec.

10°

666 sec.

Defl. voltages:

3 V/cm - want 20 cm

\[ \pm 30 \text{V} \]

3 pt 30V 1ms.

Si OK.

1ms sweep per cent

Thos. beam 2 - 10 μA.

Cathode current high 10x

100 μA.

10 pt.

1V/1ms.

Want: 100V/1ms.
Assume 1 Wav beam Energy:

10 KV

$V I = 1$

$I = 10^{-4}$ amp $= 100 \mu A$ - total.

Electron velocity at 10^4 volts

1 Electron mass $= 5 \text{ mev}$

$v = \frac{E}{m} = \frac{5 \times 10^{-6}}{4} = \frac{5 \times 10^{-8}}{\text{cm/sec}}$

for defl. plates 1 cm long

$\Delta t = 2 \text{ ns}$.

Time constants - changing.

Plate capacitance 1 pt

$L = 10^{-3}$ $\mu F$ $t = 10^{-9}$ sec

To achieve 100 V defl. voltage.

Need 100 mA current.

or mult. of 1000.