Germanium Alloy Transistors

A bit of history

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IBM Pictures

[Germanium Alloy Transistors were used on the SMS cards used in the 1401 and many early IBM transistor based computers.]

The IBM 083, NPN, alloy junction (equiv 2N1302), used in most of the SMS logic cards. (Thanks to IBM Almaden machine shop for cleanly decapitating.) Words and music on image & below by Rick Dill ;-))

The round germanium die worked for the alloy transistor because it was uniformly doped and didn't matter which side was used for emitter and base. When the diffused base transistors were introduced, the same machine could turn them out with lots of adjustments, but no major re-engineering. The die for the diffused base transistors had a unique shape without mirror symmetry so that the parts could be fed proper side up by the Syntron bowl feeders.

> The parts were sonically driven up a long spiral track to the point where they were dispensed to the handler that put the die into the fixture. Notches and other features on the track would derail any die that was upside down of any other anomaly such as a couple of emitter or collector spheres which were stuck together and not free.

View of the emitter side. Note the alignment tab, the closest tab on the case base, to aid machine testing and also machine insertion into circuit cards. Very common for this "TO-5" very popular package. TO-5

The IBM 108, PNP, used to drive a 1403 print hammer.

> Rick Dill adds "This transistor has a "ring" shaped emitter with a base contact inside and outside. In power transistors, most of the current flows right at the edge of the emitter due to base resistance drop as one gets farther from the edge. The ring gives lots of edge with relatively less inactive area.
> "The collector is probably a circular alloy "dot" which is direct soldered to the can for heat sink purposes.
> "I am not sure whether this transistor was IBM design of whether it came from Delco or Motorola who were into power transistors for car radios and other potential automotive applications."

Rick Dill 2008 - e-mails

From: Rick Dill < rdill@cyburban.com >
09/03/2008 10:12 AM
To Robert B Garner/Almaden/IBM@IBMUS
cc: ...
Subject Alloy Transistors

Robert,

The early 1950's were an interesting time. In the summer of 1951, Bell Labs had a "summer school" for a fair sized group of university professors. The professor who taught optics attended and had lectures from the likes of Shockley and Bardeen as well as some laboratory hands on time. They published a paper with everyone as an author in which they confirmed the Einstein Relationship between drift of electrons and holes under electric field and thermal diffusion. They returned to campus with a small kit of experiments which a fellow student, Jim Boyden and I latched onto and used both for recreation and every opportunity for a project. We were sophomores when we got our hands on this.

It included a germanium alloy diode for measuring IV curves, a chip of germanium with rhodium plating on the back (which we had to learn how to replace after etching it off) to be used for making point contact transistors, and a bar of germanium for the Shockley Hall measurement of drift and diffusion of electrons. We fabricated our own point contacts and crude manipulators to put them down near where we wanted them.

In the summer of 1954. fresh with a B.S. in physics I had a job at IBM in Poughkeepsie. It was my first industrial research experience and a wonderful experience. Joe Logue was the manager of the small group which included Hannon York, the engineer who invented the current switch circuit (non-saturating), Bob Henle who was a really good circuit guy and lead the company a few years later to abandon core memories and go to semiconductor memories.

At the time, the group was just off of the CRT based electrostatic memories used in the 701 and the later mica target CRT-like memories used in the following computers up to the introduction of magnetic cores which were just coming visible in 1954.

My assignment was really a gift. Joe wanted higher function circuits with the example being the neon ring counter. As he has told you, with no real hands on experience I was able to postulate that we might be able to produce such a thing with a double-based diode (unijunction transistor) which had multiple emitters and with the help of the small group in the pickle factory actually get a four-state device prototyped. Dick Rutz and John Marinace were the key people in that group and I eventually ended up working for in Rutz's group.

I also postulated an adder circuit based upon the Shockley Hall structure, but with deflectors to steer the electron cloud sideways to multiple collectors. We didn't make this, but it did show up a decade later as an academic achievement.

While Bell Labs was stuck on point contact transistors (and even made a computer out of them), Joe Logue has recognized the superiority of junction transistors. From a circuit standpoint, the ones available had too much base resistance to work well in digital circuits, although this didn't hamper them for communications. He tried to encourage the vendors to make transistors with low base resistance to little avail since computers were not important to the electronics world at that time.

The task got handed to Research where on the fabrication side the team of Rutz and Marinace and their technicians made alloy transistors with a small alloy emitter surrounded by a circular base contact, and a larger collector junction on the back side of the die. Contrary to what most people believed, alloying was a well determined metallurgical process when done right.

To do it right, you needed the crystal to have a <111> orientation. This is the slow dissolving direction when subject to dissolution by molten metal, so the sides of the dissolved region were angled along <111> planes and the bottom flat. The depth depended on the volume of the alloy "dot" and the temperature. On cooling, the germanium first cleanly regrew precipitated from the melt and was doped by the materials in the dot (indium gallium for PNP transistors and tin antimony for NPN). The collector on the backside was simply larger and etched more deeply into the germanium chip.

The design was IBM's, but we went to TI and contracted with them to manufacture germanium transistors for us. We were allowed only to make 10% of what we needed, which gave us room for special applications such as core drivers or advanced devices before releasing them to TI.

In spite of Joe Logue trying to get me to stay and do graduate work in the Syracuse MS program, I went back to Carnegie Tech and moved from physics to EE. 18 months after that Bob Henle visited campus following up on a summer job one of the young faculty had a year after me. IBM wrote three separate contracts. One supported my research with the requirement that I come to Poughkeepsie roughly monthly to report on my progress. The other two supported Dale Critchlow, the young faculty member, and Bob Dennard, one of his students. Both Dale and Bob were working in magnetics at the time. I was the first to join IBM in February 1958 and Critchlow and Dennard joined the following summer. We were all in the same group trying to do circuits with multi-hole magnetics and transistors. I left that project in summer of 1958 to go to Poughkeepsie and work for Dick Rutz with my initial assignment being to duplicate Esaki's work in Japan on tunnel diodes.

In 1955, I worked at RCA Labs for the summer on silicon diodes and the observation that they did not behave according to Shockley's theory. There I met Herb Kroemer who is credited (among other things) as the father of the "drift transistor". Kroemer postulated (as a theorist) that a graded impurity doping in the base region would provide a field that greatly speed up transistors. It was only after I got to IBM that I read a patent of Lloyd Hunter which is the patent on the structure, so IBM has at least as much claim as RCA. By diffusing (probably phosphorus) into the germanium blanks, the IBM design became much faster.

In 1958 on returning to IBM, I found that the development group had built a fully automated factory for producing alloy transistors. It used syntron sonic driven bowls to feed to germanium die, alloy spheres for emitter and collector, stub leads soldered to the spheres during alloying, and the dished base contact washer. These were fed into high purity carbon fixtures, one for each transistor. Once the assembly was together it went through a hydrogen furnace, after which the transistor was extracted, etched, washed, dried, tested, and then assembled onto a header. The carbon fixture was sent back to be re-used. This room-sized automated factory could product 40 million transistors a year, which was more than IBM needed. We shipped the factory to TI with the stipulation that they could use it only for IBM production for a stated number of years.

When the diffused base transistor came in, it was only a small modification to the line to get the die right-side-up so that the diffused surface was facing the emitter.

About 1964 I visited TI and saw multiples of this production facility running full tilt to make germanium transistors for the world.

Silicon really came in with the system 360. The group that met to work out what would be done was the Compact Committee. I was a research rep on that team. We should talk about that sometime. Bill Harding was one of the key people and I believe that he is still around in Southern CA. What became solid logic technology (SLT) came from his declaration that

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he could produce individual transistors very cheaply and solder them
directly to substrates.  This was all an act of faith, but it came to
fruition and significantly delayed IBM's serious entry into integrated
circuits for logic.

When we did get into integrated circuits for logic, electron beam
lithography played an immense role in giving IBM a competitive
advantage.  Hans Pfeiffer was the leader in this technology and is now
in Carmel Valley.

This is just a little background for ou[r] Thursday discussion.

Rick
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After the meeting with Rick, Robert Garner wrote

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I met with Rick for 3 hours today.
He was a PhD summer intern at IBM in 1954,
    working on multi-emitter Germanium devices.
Fascinating conversation on all what was going on a IBM at the time (and later).
He thinks he can  explain our loopy I-V curves
    (water contamination causing the usual culprit - surface states.)


Finally I have someone to talk to about the physics and manufacturing
    of our alloy junction transistors. (although I have some old books on topic now too.)
He also talked about how hard it was to make the
    high-voltage core/hammer driver power Ge transistors...


- Robert
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Rick Dill 2010 - e-mails

On 11/29/2010 12:13 PM, William Donzelli wrote to *cctalk@classiccmp.org* and Robert Garner responded:

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>> Have you seen early Philco transistors -- "look a bit like bullets
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>>   - about 1/2 inch long, and maybe 3/16 inch diameter,
>>      metal with a rounded top" -- on any SMS cards?
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> A Google image search of 2N501 will show somw Philcos.
>
>> (I can send higher-res versions of these pics if you need.)
> Yes, please. On early transistors, sometimes the distinguishing marks
> for each manufacturer are very subtle.
>
> Thanks!
>
> --
> Will
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From: Rick Dill
Date: Tue, Nov 30, 2010 7:38 pm

Hi all,

Sorry for the late response, but I've been off-line for a couple of days in the Sierra.

Philco had some of the most interesting transistors of the 50's era. There were three families as the technology developed.

All their transistors were made by a very interesting process. They started with the germanium die connected the the base contact ring in an manner essentially identical to the IBM germanium transistors you are used to.

This is then placed between two glass capillaries which served as fluid nozzles for very fine jets of fluid. The two nozzles differed in diameter and diameter of stream with the one on the collector side being larger.

These are used to get two jets of electrolyte impinging on the two exposed sides of the die. The fluid is an electrolyte which contains both indium and gallium in solution. A voltage is applied between the base ring (die) and electrodes in each nozzle. Initially, the polarity used causes electrolytic etching of the germanium, creating relatively smooth flat bottomed indentations from the two sides of the die, with the collector being deeper and wider.

This etching process is monitored by an infrared beam which goes through the fluid and nozzles. When the infrared transmission rises enough, the etch process is stopped and the current reversed. This plates a thin metallic film of indium/gallium (mostly indium) circular film. Leads are attached to these films for the emitter and collector contacts. The resultant transistor is packaged in the "tiny bullets" observed. The base region could be etched down to where it was very thin with an accurately controlled thickness.

The first of these was the "surface barrier" transistor. It used the metal-semiconductor barrier (schottky barrier) for the emitter and collector. This worked OK for the collector, but the emitter wasn't very efficient and the transistors had low current gain compared to competitors. Where they won was on high frequency response.

The next step was to run the finished transistors through a very brief thermal cycle and to slightly "alloy" the emitter and collector films into the germanium. This produced consistent high frequency transistors that were superior to anything on the market. The drawback was that they were fragile because of the very thin membrane base. In the summer of 1954, when I was a summer employee, the circuit team under Joe Logue was investigating these (Jim Walsh, Bob Henle, Jim Mackay, and Hannon Yourke). They ended up rejecting the Philco SBT and Micro-Alloy transistors because of ruggedness concerns.

In 1955, I was at RCA Labs for the summer. My assignment was to look at the forward I/V curves of silicon diodes (which I made). They did not follow Shockley's theory! That was explained a few years later in a classic paper by Shockley, Noyce, and Sah,

A new employee at RCA Labs was Herb Kroemer, just arrived from Germany where he had published a paper on the "drift" or diffused base transistor. Kroemer had correctly worked out the physics which showed that a base region which had an impurity grading from highly doped on the emitter side to low on the collector side would have an internal electric field which would propel minority carriers from the emitter to the collector. RCA immediately put these into manufacturing, as did many including IBM which modified the automated transistor machine to make them.

The actual patent for the graded base structure was actually held by IBM. More on that later!

Philco was quickly able to adapt their process to work with a die which had the base region diffused from one side. They adapted their etching so that the emitter etch depth was very small, while the collector etched deeply into the die. Again, their IR control allowed them precision control of the physical width of the base membrane. This was called the "micro-alloy diffused transistor". Exceedingly good performance for the day, but they continued to be mechanically fragile.

I probably have some philco transistors in my collection. One of these days, I will unearth that and see what is of interest to the computer history museum.

Rick Dill