LB-988

ALLOYED JUNCTION TYPE N-P-N GERMANIUM-SILICON TRANSISTORS

RADIO CORPORATION OF AMERICA
RCA LABORATORIES DIVISION
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By controlling the proportion of silicon in a germanium-silicon alloy, the width of the forbidden energy band may be varied between the value for germanium (0.72 ev) to that for silicon (1.2 ev). For example single crystals have been grown with 12 molecular per cent silicon[1] with an energy gap of 0.92 ev. Many of the other properties of this material are also intermediate between those of germanium and silicon. In transistors, such alloys may permit a closer approach to the high-temperature characteristics of silicon without departing too widely from other characteristics more typical of germanium. This bulletin will describe preliminary experiments on p-n-p transistors made by alloying junctions on a germanium-silicon base wafer.

The transistors were prepared from germanium-silicon alloys having silicon content in the range 2.5 to 6 mol per cent. The collector-to-base current-gain factor ranged from 9 to 25 while the low-frequency power gain ranged from 24 to 39 db. The behavior of these units at elevated temperatures did not show as much reduction in reverse saturation current as would have been predicted from the increased band gap. This is attributed to surface leakage effects. The current-gain factor was found to increase with increasing temperature. Power gains were relatively unaffected by increasing temperature.

Fabrication

Junctions were prepared on the germanium-silicon material by an alloying process similar to that in common use in the preparation of junctions on p-type germanium. Refinements developed for application to germanium-silicon material are discussed below.

The single crystal germanium-silicon material was grown in the (111) direction by a horizontal zone-melting process. Optical absorption measurements of the energy gap in each crystal gave an indication of the percentage of silicon. Bulk lifetime was measured by examining the recombination of carriers generated by a light pulse. The materials used came from three crystals, here designated as A, B and C. The bulk properties of these crystals were as follows:

CRYSTAL	SILICON mol %	BAND GAP e.v.	P-TYPE RESISTIVITY ohm-cm	BULK LIFETIME μsec
A	6	.81	4-4.5	10-15
B	3-6	.76-.81	2.2	15-75
C	2.5	.75	1.5-2.5	40

Crystals were cut and ground into pellets 0.150 inch square and 0.012 to 0.015 inch thick. These pellets were etched to the desired thickness (3.8 to 4.3 mils) in CP-4 etch[2] immediately before fabrication.

[1] *LB-949, Some Properties of Germanium-Silicon Alloy Semiconductors.*

Emitter and collector dots were 10 weight per cent antimony in lead. Dots were cylindrical and 15 mils thick, the emitter dot 15 mils in diameter, the collector dot 40 or 45 mils in diameter. The dots were cleaned in dilute hydrochloric acid and, just prior to firing, were rinsed in concentrated hydrofluoric acid. The unit was assembled in a graphite boat with both dots held in place by 13-mil thick graphite washers for simultaneous firing. Firing temperatures ranged from 700 to 740 degrees C, depending on the pellet thickness. The units were fired for 4 minutes, then cooled at a rate of 75 degrees C a minute. All firing was done in an atmosphere of 10 per cent hydrogen, 90 per cent nitrogen.

After the dots had been fired, the base tab was separately fired on using Pb-Sn-In solder. As with the dots, an HF rinse was used just prior to firing. The base tab was positioned 25 to 50 mils from the emitter dot, and fired at 550 degrees C for three minutes. Cooling was as before.

The assembled transistors were etched very briefly in CP-4 etch,[2] great care being exercised to keep the base tab out of the etch. The first units made were rinsed in Etch No. 3[2] after the etch in CP-4. This was found not to be necessary. Various electrolytic etches were tried, but none proved as repeatedly reliable as the CP-4 etch. After the etch, the units were rinsed in distilled water and blown dry in an air jet. The units were kept in a desiccated atmosphere until encapsulation. Units were potted in the Araldite E-272 compound of the Ciba Company. It was found necessary to re-etch the units between mounting and encapsulation.

Room Temperature Characteristics

The characteristics to be described below are typical of the better units. Observations indicate that the recombination velocity of germanium-silicon surfaces is higher than that observed with germanium. This, and imperfect alignment of the emitter and collector, tended to reduce the current gain. A comparison of values of α_{cb}, the collector-base current amplification factor, at 4 kc, and the 4-kc power gain is given below for germanium-silicon units containing various amounts of silicon.

NO. OF UNITS TESTED	SILICON mol %	α_{cb}*	PG* (db)
6	6	11-19	24-33
8	3-6	9-25	29-35
1	2.5	19	39

*Measured at E_c = +6 volts, I_e = 5 milliamperes.

Thinner pellets (3.8 to 4.2 mils) heated at a lower temperature (700°C) gave units of higher current gain than 5 mil pellets heated to 750 degrees C, although the effective base widths were of the same order. This may be a result of the smaller emitter penetration[3] required on the thin pellets or due to a lowering of the bulk lifetimes at the higher temperature. Pellets thinner than 3.5 mils were found to be impractical because of the difficulty encountered in handling them.

High Temperature Performance

The reverse current of both junctions, the 4-kc power gain and α_{cb} were measured for 4 germanium-silicon units at temperatures ranging from room temperature to 80 degrees C. An experimental n-p-n germanium transistor (alloy type) was also tested as a control. Fig. 1 shows the reverse current at plus 2.5 volts as a function of temperature for transistors made from the 2.5 per cent alloy and the 3-6 per cent alloy, and also for the germanium unit. The reduction in the value of the reverse current with the addition of silicon is not as great as that anticipated from a theoretical consideration of the saturation current. It is likely that the reverse currents measured contain large components due to surface leakage and that they, therefore, do not represent the true saturation currents of the transistors involved.

[2] *LB-903, A Germanium N-P-N Transistor by the Alloy Process.* (The CP4 and the No. 3 etch are referred to as 1st and 2nd etch respectively.)

[3] *LB-966, The Variation of Current Gain with Junction Shape and Surface Recombination in Alloy Transistors - Part II.*

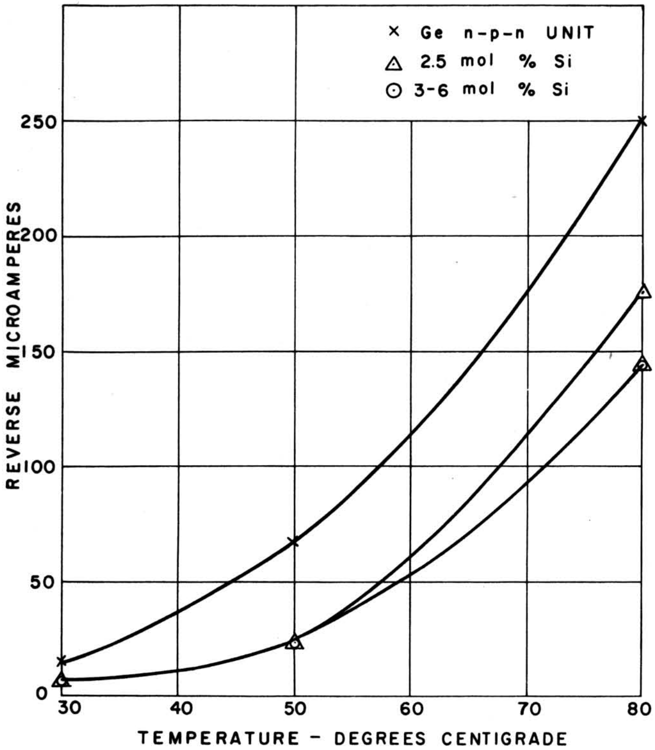

Fig. 1 - Reverse current as a function of temperature.

Another comparison between the germanium-silicon alloy units and the germanium control unit is given in Figs. 2 and 3, where α_{cb} and power gain are plotted as functions of temperature. The germanium-silicon units exhibit an increase in α_{cb} with increased temperature[4] while the germanium unit shows a constant α_{cb} to 80 degrees C and a decrease at higher temperatures. With regard to power gain, the differences are not significant.

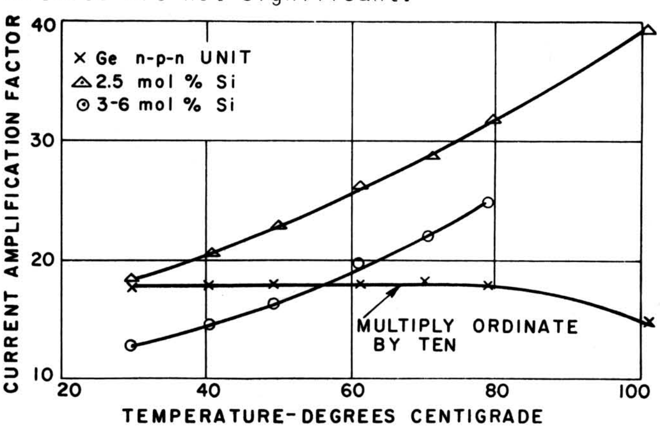

Fig. 2 - Current amplification factor as a function of temperature.

[4]This is also true for silicon, as reported in *LB-952, Silicon N-P-N Junction Transistor by the Alloy Process.*

The effective lifetime[5] of the germanium-silicon units as well as that of the germanium control unit was found to increase with temperature. The 2.5 mol per cent alloy unit exhibited a lifetime of 1.5 μseconds at 80 degrees C. The germanium unit showed lifetimes of 6 and 10 microseconds at 30 and 80 degrees C respectively.

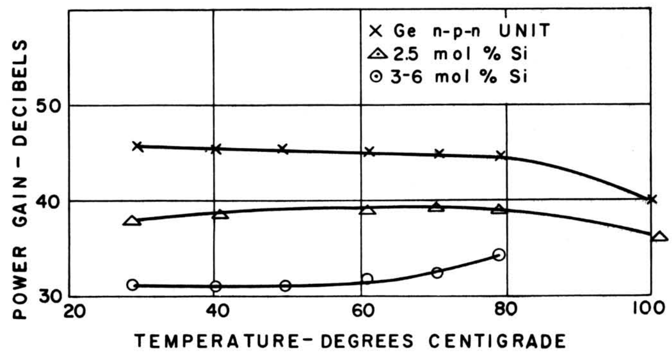

Fig. 3 - Power gain as a function of temperature.

Conclusions

Operable transistors have been prepared from p-type germanium-silicon alloys having silicon contents in the range of 2.5 to 6 mol per cent. The collector-to-base current-gain factor, α_{cb}, has ranged from 9 to 25 while the low-frequency power gain has ranged from 24 to 39 db. In some respects these transistors respond to increased ambient temperature more in the manner of silicon units than in that of germanium units. The reduction in the value of the reverse current expected as a consequence of increased bandwidth has not been realized, however. This is probably a consequence of the particular surface treatment employed and is not regarded as significant with respect to the basic properties of the bulk material.

[5]*LB-934, Measurement of Minority Carrier Lifetime and Surface Effects in Junction Devices.*

Herbert Nelson

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