LB-805

EFFECTS OF CONTACT PRESSURE ON TRANSISTOR GAIN

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Approved

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SUMMARY

Following the observation that transistor gain maximizes as the electrode contact force is increased, the effects of pressure were studied at each electrode, using tungsten and phosphor bronze probes. The spring constant of the probe was measured so as to determine the contact force from a compression measurement.

Measurements made on formed high gain units showed only negligible gain variations with pressure. However, it was found that in unformed units the power amplification A varies according to the following empirical formula:

$$A = A_0 \, \varepsilon^{-kP_c} \, P_e^m$$

where A_0, k, m *are constants and* P_c *and* P_e *are the collector and the emitter pressures, respectively. The maximum gain will be obtained when the emitter pressure is maximum (yield pressure of probe material) and the collector pressure is a minimum (but sufficient for a stable contact). When both pressures are equal and adjusted simultaneously, a maximum gain occurs at an optimum pressure.*

An increase in emitter contact area induces no change in gain while an increase in collector contact area reduces the gain.

Effects of Contact Pressure on Transistor Gain

Introduction

While experimenting with novel transistor constructions it had been observed that the electrical characteristics of the unit varied with the force pressing the electrodes against the active surface of the crystal. It was especially noticed that there was an optimum pressing force at which the gain is maximum. In order to investigate this phenomenon more critically a series of experiments was performed in which the transistor characteristics could be studied as a function of the pressure at each electrode. This bulletin discusses these experiments and the data obtained.

Pressure Calibration

Since the electrodes are sharply pointed the contact area is extremely small and the pressure developed at the contact may be extremely large, in fact it may exceed the yield point of the materials involved, in which case the contact area increases. Germanium being much harder than the electrode material it is fair to assume that all the deformation takes place in the electrode. Furthermore, we may assume that the deformation is irreversible since any observable deformation takes place only after the yield point has been exceeded.

The deformation of the point was measured with a high magnification microscope while the probe was pressed against a glass plate with a known force. The contacting area has well defined boundaries but some estimation is necessary in order to take into account the irregularities of the configuration.

The set up for measuring contact deformation is illustrated in Fig. 1. The probe consisted of a 10 mil wire one end of which was ground to a 45 degree "chisel point".

The contact area was plotted against the pressing force. The inverse slope of the straight line thus obtained gives the yield pressure of the probe.

$$\text{Yield Pressure} = \frac{\text{Pressing Force}}{\text{Contact area}}$$

Measurements made on tungsten and on phosphor bronze wires gave the following yield pressures:

Tungsten: 20×10^6 dynes/cm^2

Phosphor Bronze: 7.2×10^6 dynes/cm^2

The contact area ranged between 10^{-6} and 4×10^{-5} cm^2.

Since it was more convenient to measure displacements in a rigid system than forces in a balanced system, the probes were shaped into standardized springs, the compression of which was calibrated in terms of the pressing force. The shape of the probe was the one illustrated in Fig. 2, and the pressure calibration was performed as shown in Fig. 3.

These measurements produced the following data:

	Spring Constant	Elastic Limit
Tungsten:	35.7 dynes/mil	275 dynes
Phosphor Bronze:	10 dynes/mil	135 dynes

Thus, starting with a fresh probe, the contact area can be determined from the knowledge of the pressing force which is measured as a compression of the spring since initially the contact is at yield pressure. Then if the pressing force is reduced the contact area remains constant and the compression of the spring indicates the pressing force at the contact. Then the contact pressure is simply the ratio of the pressing force to the contact area. If the compression is increased up to its previous maximum value the pressure increases to the yield value. However, further increase of the pressing force results in an increase of contact area at the constant yield pressure.

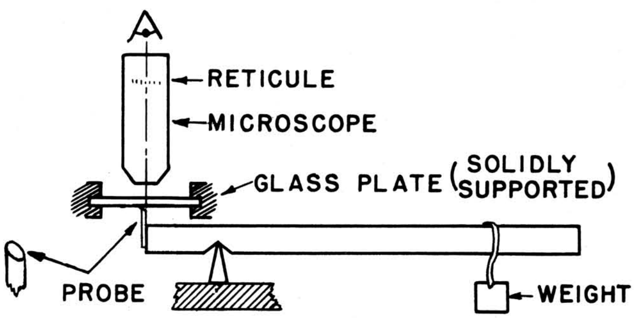

Fig. 1 - Set-up for measuring contact deformation.

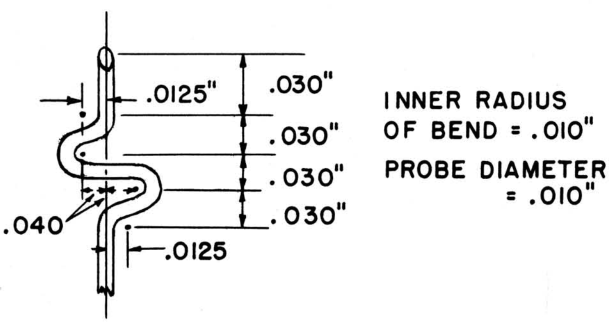

Fig. 2 - Shape of the probe.

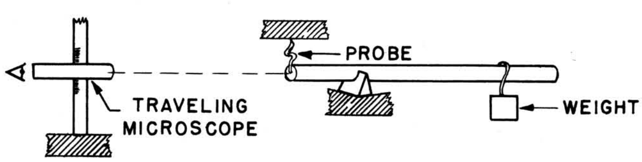

Fig. 3 - Calibration of the spring constant.

Pressure Effects on Transistor Characteristics

The transistor was assembled in the apparatus shown in Fig. 4. The probes are mounted at the end of two beams and are initially adjusted to provide a 2 mil spacing between the points. Then the crystal is moved up by means of a micrometer screw adjustment until it contacts the probes -- this is detected by means of an ohmmeter connected to the base of the crystal and to the two probes. The calibrated screw deflects each beam by a known amount, the leverage ratio being such that the compression at the probe is one-fourth of the screw's longitudinal displacement. Thus a compression of 0.00025 inch is reproducible. "C" shaped springs at the end of each beam work against the micrometric screws to eliminate any play.

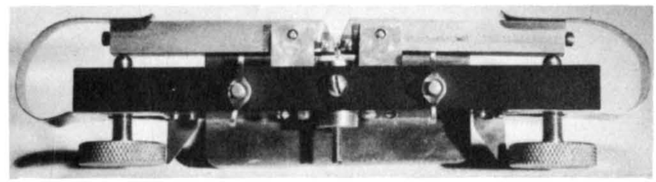

Fig. 4 - Pressure apparatus used in this study

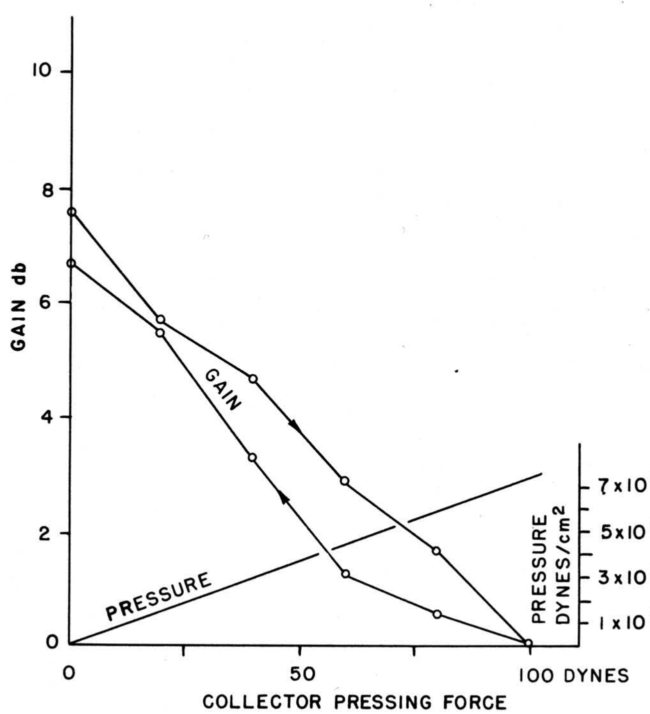

Fig. 5 - Transistor gain as a function of collector pressing force.

Measurements made on a number of units using tungsten probes as well as phosphor bronze probes show that the power gain (in decibels) is inversely proportional to the collector pressure (Fig. 5) and that the power gain is proportional to the logarithm of the emitter pressure (Figs. 6 and 7). This behavior can be summarized in the following empirical formula:

$$A = A_o \, \varepsilon^{-kP_c} \, P_e^m$$

where:

A = power amplification
A_o, k, m = constants
P_c = collector pressure
P_e = emitter pressure

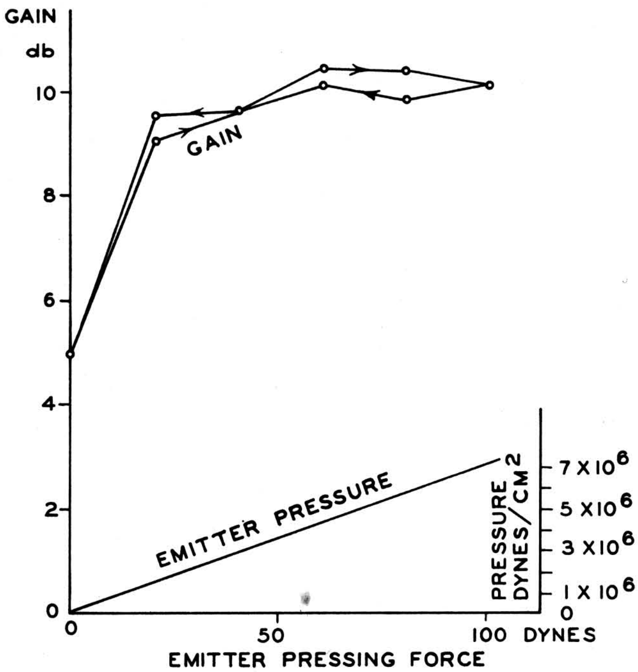

Fig. 6 - Transistor gain as a function of emitter pressing force.

The competing pressure effects which take place at the emitter and at the collector explain the observed optimum pressure which the above formula places at $P = \frac{m}{k}$ (when the same pressure is applied at the emitter and collector contacts).

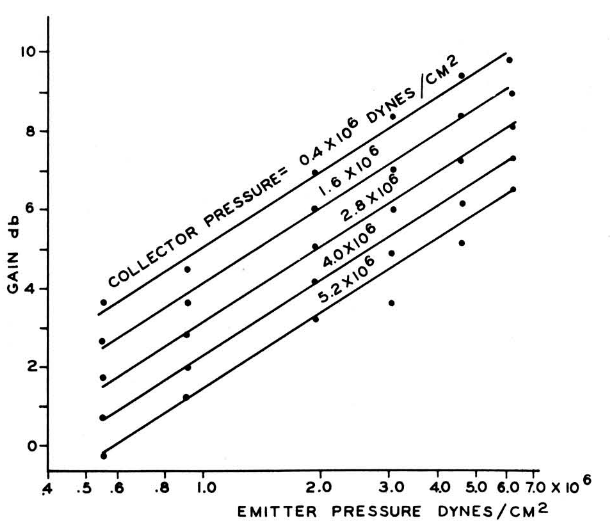

Fig. 7 - Transistor gain as a function of emitter pressure for different collector pressures.

Fig. 8 shows that transistors using phosphor bronze probes are more pressure sensitive than those using tungsten probes.

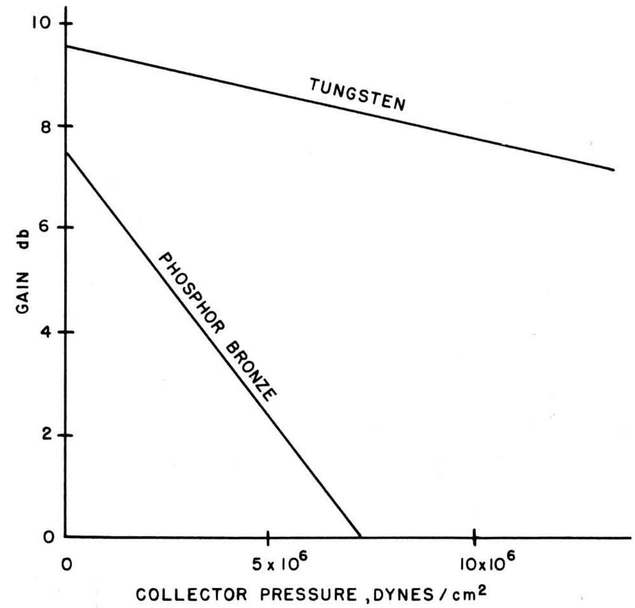

Fig. 8 - Comparative presentation idealized from best experimental curves.

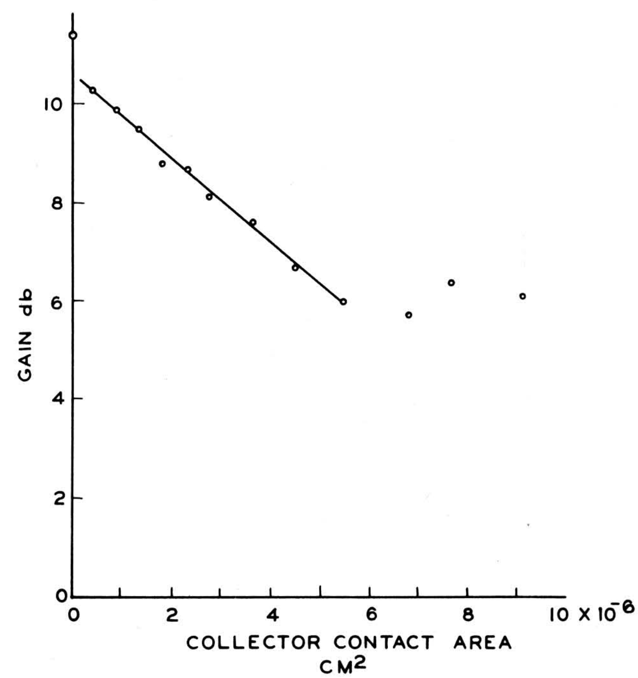

Fig. 9 - Transistor gain as a function of collector contact area at yield pressures.

An increase in emitter contact area (by increasing the contact force beyond the yield pressure) induces no significant change in the gain while an increase in collector area reduces the gain (Fig. 9). This suggests the possibility that pressure effects actually result from submicroscopic changes in area which determine the "intimacy of the contact".

The pressure effects herein reported were observed on units which had a maximum gain of about 10 db. On the other hand, tests made on a number of formed high gain units exhibit only a negligible variation of gain with contact pressure.

Such a pressure independence might be due to the still hypothetical fact that a formed contact expands its zone of sensitivity beyond the actual metal-semiconductor boundary. Any pressure variation at the "contact boundary" would then be considerably reduced at the "sensitive boundary".

Conclusions

The power gain of unformed transistors depends on the pressure at the contact electrodes. The maximum gain that can be obtained by controlling the contact pressures will occur when the emitter pressure is maximum, and the collector pressure minimum. The maximum pressure is the yield pressure of the probe material (the germanium is usually much harder); the minimum pressure is that which will be sufficient for a stable contact. These effects do not apply to formed high gain transistors.

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