D. R. Young
D. P. Seraphim

Surface Effects on Silicon: Introduction*

As early as 1948, Shockley and Pearson[1] showed that the conductivity of an evaporated germanium film could be modulated by means of an electric field applied normal to the surface. One surprising result of this work was that only about 10% of the charge induced by the field contributed to the conductivity. The reason for this discrepancy was explained by J. Bardeen as being due to the presence of surface states that immobilize the induced charge.[2]

The effect of the semiconductor surface on bipolar transistor characteristics was clearly demonstrated by W. L. Brown[3] as a result of his studies of emitter-to-collector leakage effects in germanium *n-p-n* transistors. He explained the leakage in terms of the formation of an *n*-type channel on the surface of the *p*-type germanium used for the base of the transistor. Since this work, many papers have been written on the effect of the surface on semiconductor device characteristics but it will suffice to cite a few key publications. The effect of *n*-type channels on the reverse current in germanium *p-n* junction diodes has been studied by McWhorter and Kingston.[4] Surface leakage currents have also been observed in silicon junction diodes by Cutler and Bath.[5] Garrett and Brattain have shown that the surface can even control the breakdown voltage in *n-p-n* transistors.[6] Recently, Sah[7] has shown that the current gain of transistors can be controlled by means of the surface. In the case of the insulated gate field-effect transistor, the location of the characteristics on the gate voltage axis and the small signal transconductance are both determined by the surface.[8]

The work that has been cited clearly demonstrates that the behavior of semiconducting devices is sensitive to surface conditions and that long-term stability of device characteristics requires that the surface conditions remain constant. In the past, this has been accomplished by encapsulating the devices in a hermetically sealed container. Even when these precautions have been taken, instabilities in device characteristics due to surface effects have been observed. One effect of this type has been reported by Peck et al.[9] as being due to ions flowing to the surface of the device. The gas in the device capsule was ionized by the incident radiation.

In 1959, Atalla, Scheibner and Tannenbaum[10] showed that the sensitivity of silicon devices to ambient effects can be significantly reduced if the devices are protected by a *thin film of silicon dioxide grown in situ.* As a result of their observations, considerable work has been done on the use of silicon dioxide as well as other dielectric materials for device protection. Modern trends in planar silicon device construction use this technique.

The work that has been done to date makes it possible to

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specify the electrical requirements of an ideal passivating layer as follows:

1. The semiconductor surface potential[11] must not change significantly with time under the stress conditions that are encountered by the device.
2. The semiconductor surface potential should be optimum for the particular device under consideration.
3. Some types of devices require reasonably small values of the surface density and the surface recombination velocity. These characteristics are also influenced by the passivation.

The several papers on surface effects that are included in this issue of the IBM JOURNAL are concerned with effects that are relevant to these requirements. Generally, the aim is to summarize the results of work by the IBM Components and Research Divisions toward understanding the role of the insulator or passivating layer in determining the surface potential, and to discuss treatments which have been devised to control and improve device characteristics. Certain of the effects are discussed and described in terms of models devised in the course of the work; others are treated because of their topical technical interest and in anticipation that satisfactory theoretical interpretations will be stimulated from work in process.

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10. Atalla, Scheibner and Tannenbaum, "Stabilization of Silicon Surfaces by Thermally Grown Oxides," *Bell System Tech. J.* **38**, 749 (1959).
11. The semiconductor surface potential determines the number of holes and electrons present in the surface space charge layer. For a definition, see the paper by R. H. Kingston and S. F. Neustedter, "Calculation of the Space Charge, Electric Field, and Free Carrier Concentration at the Surface of a Semiconductor," *J. of Appl. Physics* **26**, 718–720 (1953).