Correspondence

Silicon *P-N* Junction Power Rectifiers and Lightning Protectors*

Silicon possesses a number of properties which make it of considerable interest for use in semiconducting devices. Silicon *p-n* junction rectifiers have reverse currents at least 1,000 times smaller than those of germanium. Temperature rises of at least 150 degrees C. above room temperature may be tolerated with silicon, whereas germanium and other semiconducting rectifiers are limited to about 40 degrees C. rise. At reverse voltages above breakdown silicon *p-n* junctions show remarkably flat voltage saturation characteristics, and the breakdown voltage is controllable over a range from a few volts to several hundred volts.

The above characteristics are now available in small area silicon *p-n* junction alloy devices.[1] Although the outstanding characteristics of silicon *p-n* junction devices have been understood for sometime, the inability to fabricate large area junctions as well as to make low resistance contacts to silicon surfaces has prevented the fabrication of higher power devices. The present article describes a new method for preparing large area silicon *p-n* junctions and gives the electrical characteristics of two power devices prepared by this method. Although both are still in the experimental stage, their properties seem sufficiently promising to report at this time.

Diffusion Technique: The new technique, which will be described more fully elsewhere, consists of diffusing donor (e.g. phosphorus) or acceptor (e.g. boron) impurities into high purity single crystal silicon[2] surfaces at temperatures above 1000 degrees C. Planar layers of controllable thicknesses up to a few mils may be produced in this manner, and the area is limited only by the size of the silicon ingot. The barriers prepared in this way not only possess excellent reverse current and voltage saturation properties, but also the resistivities of the diffused layers are as low as 0.001 ohm cm. This low resistivity surface layer permits the direct application of metallized contacts thus solving in a simple manner the difficult problems of making contact to silicon. The technique described above has already been utilized to produce a highly efficient silicon photocell for the conversion of solar radiation to electrical power.[3]

Power Rectifiers: Semiconducting power rectifiers currently in use are fabricated mainly from copper oxide, selenium, and germanium. The first two of these materials are limited to fairly low reverse voltages and none of them operates satisfactorily at temperatures above 70 degrees C. Fig. 1(a) indicates the configuration of a completed silicon single-cell *p-n* junction rectifier. Acceptor impurities are diffused into one side of an *n*-type silicon slab to form the *p-n* junction and the low resistivity *p*-type layer. Donor impurities are diffused into the opposite side to form a low resistivity *n*-type surface layer. Both sides are then metallized and the unit is pressed between metal electrodes. Fig. 2 is a plot of the static current versus voltage characteristics of such a unit having an area of approximately 0.75 cm^2. Curves are given for continuous operation at ambient temperatures of 27 degrees C., 100 degrees C., and 150 degrees C. Forward currents up to 20 amperes were obtained with an over-all forward resistance of .08 ohms. As a power rectifier operating into a resistance load the efficiency is somewhat better than 95 per cent. Because of the small reverse currents, the loss comes almost entirely in the forward direction. Although the maximum reverse voltage of this unit is about 85 volts, this may be varied through a choice of the silicon ingot resistivity.

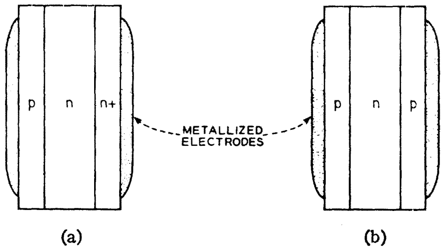

Fig. 1—Configurations of large area silicon *p-n* junction power devices; a. power rectifier, b. lightning protector.

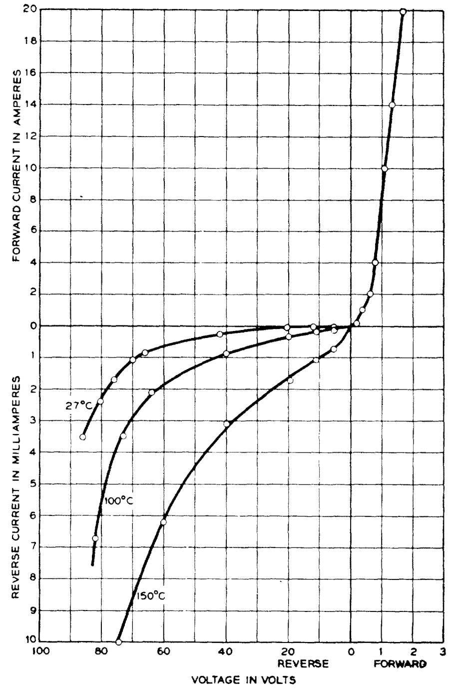

Fig. 2—Static current versus voltage characteristic of silicon *p-n* junction power rectifier.

Lightning Protectors: Lightning protectors dissipate the energy of high voltage surges but allow equipment which they are protecting to function normally under ordinary operating conditions. A large area silicon *p-n-p* junction as shown in Fig. 1(b) is ideal for this purpose. It has a high resistance at all voltages below breakdown, but under high current surges the voltage rise is limited. The protector is equally effective for surges of either polarity and will dissipate the energy of high amperage pulses of short duration such as those present in lightning surges. The protector is made by diffusing acceptor impurities into both sides of an *n*-type silicon slab thus forming two opposing *p-n* junctions. The electrical characteristics of such a protector are shown in Fig. 3. Although the saturation voltage of the unit shown here is 95 volts, this value has been varied from 30 to 200 volts through a choice of the silicon-ingot resistivity. Fig. 3(a) gives the static current voltage characteristic at low currents and Fig. 3(b) the voltage limiting characteristic in the saturation range for 20 microsecond duration current pulses as high as 5,000 amperes. The voltage rise at high currents is due mainly to the resistance of the *n*-type layer which amounts to 0.05 ohms in this unit.

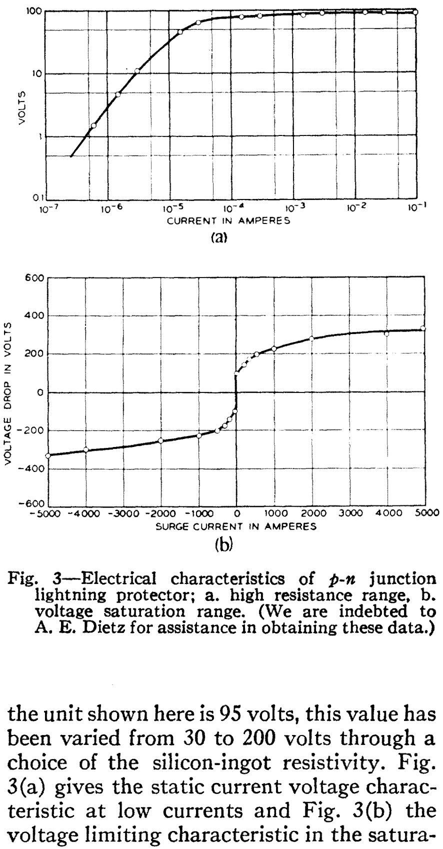

Fig. 3—Electrical characteristics of *p-n* junction lightning protector; a. high resistance range, b. voltage saturation range. (We are indebted to A. E. Dietz for assistance in obtaining these data.)

Conclusion: Although the silicon *p-n* junction devices described in this paper are still in the experimental stage, they show promise of contributing greatly to the technology of power rectification and lightning protection.

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[2] G. K. Teal and E. Buehler, "Growth of silicon single crystals and of single crystal silicon *p-n* junctions," *Phys. Rev.*, vol. 87, p. 190; July, 1952.

[3] D. M. Chapin, C. S. Fuller, and G. L. Pearson, "A new silicon *p-n* junction photocell for converting solar radiation into electrical power," *Jour. Appl. Phys.* (In press). Presented orally by D. M. Chapin at AIMME annual meeting, New York, N. Y., February 15, 1954.