This Week's Citation Classic

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Irvin J C. Resistivity of bulk silicon and of diffused layers in silicon.
Bell Sys. Tech. J. **41**:387-410, 1962.

Resistivity-impurity concentration plots for n- and p-type silicon were presented, based on new as well as older data. Using these results, the relationships between surface concentration and average conductivity of diffused layers in Si were calculated for Gaussian and complementary error function distributions. [The *SCI*® indicates that this paper has been cited over 315 times since 1962.]

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"When I came to Bell Laboratories in 1957, the transistor was nine years old and commercial deployment was in its infancy. The versions then in production were mainly point contact and alloyed junction devices. Germanium was the workhorse semiconductor but the research emphasis had shifted to silicon. Diffusion technology was under intense development as were numerous designs of diffused junction, silicon transistors, the type which soon dominated the field. Basic to the design calculations for a transistor as well as to material development and to most research on the properties of silicon is the relation between the donor or acceptor concentration and the resulting electrical resistivity of bulk silicon. Also vital to the design of a diffused transistor and to the analysis of diffusion processes is the relationship between the sheet resistivity, depth, surface concentration, and profile (distribution) of a diffused layer. Several incomplete treatments of these subjects were available but were limited in both the range of parameters covered and the accuracy of the raw data employed.

"My own interest at that time was in the temperature coefficient of electrical resistance of diffused layers in Si and the means of minimizing this coefficient. In the course of this work I became aware of the shortcomings of the available resistivity relationships. Thus, with the encouragement and assistance of numerous colleagues, I embarked on a comprehensive project to obtain the needed new data reappraise the older data, plot these values for bulk silicon, and finally recompute the diffused layer properties, which were then presented graphically. The fortunate concurrence of improvements in measurement technology, other independent investigations then in progress or just completed, as well as the many measurements initiated expressly for this project made it possible to extend significantly the available data base, which was the foundation of this work.

"The timing of the resultant publication was most propitious and it proved to be a very useful tool in a rapidly expanding field. The popularity of these curves is gratifying but it has caused some workers to impute to them greater accuracy and wider application than is merited. In particular, gallium-doped silicon was used for the mid-range of the p-type curve and since Ga has a relatively large activation energy, the properties are not identical to those of boron-doped material, more common today. Also, in this and other portions of the curves, there is a significant difference between carrier and impurity concentration, making it quite erroneous to attempt to calculate mobility from these curves. Mobility is easily and accurately obtained from a later but less well-known work.[1] The importance of the relationship between impurity concentration and resistivity has not diminished over the years. A joint effort between the National Bureau of Standards and the American Society for Testing and Materials is currently underway to more precisely determine this relationship for boron and phosphorus doped silicon. However, applied with sensible caution, the 1962 graphs still appear to be quite useful and have been widely reproduced."

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1. **Sze S M & Irvin J C.** Resistivity, mobility, and impurity levels in GaAs, Ge, and Si at. 300°K. *Solid State Electron.* **11**:599-602, 1968.