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This Week's Citation Classic

Hall R N. Power rectifiers and transistors. *Proc. IRE* **40**:1512-18, 1952.
[General Electric Research Laboratory, Schenectady, NY]

PIN power rectifiers and transistors made by alloying methods show exp(qV/2kT) behavior over a wide range of current and temperature. This behavior is quantitatively reproduced by an analysis which assumes that recombination increases linearly with carrier concentration in the high-level regime. [The *SCI*® indicates that this paper has been cited over 115 times since 1961.]

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"The announcement of the transistor in 1948 by Bell Laboratories came a few months after I had joined the General Electric Research Laboratory in Schenectady. My first project was to purify Ge, and a year later I had grown a nearly perfect single crystal with a junction halfway along its length. I found that the apparent resistivity near the junction varied by orders of magnitude as I changed the current, and I thought I had discovered a new kind of rectifier based on charge injection. I called it a 'barrierless rectifier.'

"To synthesize a more efficient structure, I tried diffusing In and Sb into opposite sides of a wafer. I assembled the components, heated them with a Bunsen burner until they fused together, and was thrilled to discover that I had made a diode with excellent forward characteristics.

"I soon realized that it wasn't a barrierless rectifier, but it *was* a new structure, now known as a PIN rectifier, and it looked ideal for power applications. Before long I was building water-cooled rectifiers that handled several kilowatts and I had to have a 40 kVA transformer wired into my lab to test them. However, I found that their forward current varied as exp(qV/2kT) instead of the usual exp(qV/kT) and I couldn't explain that. I struggled for months trying to coax 2kT out of Shockley's equations, in vain. Finally I realized that it could be explained if recombination was a two-step process at an impurity level near the middle of the energy gap. Everything fell into place then. I had an analytical result that reproduced the experimental data over a wide range of temperature and eight decades of current. Furthermore, I had discovered the mechanism responsible for electron-hole recombination. PIN rectifiers were later made from silicon and their analysis has been greatly extended.[1,2]

"This paper has been frequently cited because it gave the first description and analysis of the PIN structure which evolved into the silicon rectifiers and thyristors that power much of today's electrical industry. Secondly, it disclosed a new and versatile method of forming p-n junctions by alloying. Finally, the exp(qV/2kT) behavior is a distinctive feature which has been frequently invoked to explain the electrical characteristics of other semiconductor devices."

1. **Herlet A.** The forward characteristic of silicon power rectifiers at high current densities. *Solid State Electron.* **11**:717-42, 1968.
2. **Schlangenotto H & Maeder H.** Spatial composition and injection dependence of recombination in silicon power device structures. *IEEE Trans. Electron Devices* **ED-26**:191-200, 1979.