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This Week's Citation Classic

Hilibrand J & Gold R D. Determination of the impurity distribution in junction diodes from capacitance-voltage measurements. *RCA Rev.* **21**:245-52, 1960. [RCA Laboratories, Princeton, NJ]

Reliable information on the distribution of dopants in completed semiconductor junction devices is useful in understanding device operation and in control of the fabrication process. A method to determine the impurity density level to better than 20 percent accuracy and to evaluate the impurity profile even more accurately is described. [The *SCI*® indicates that this paper has been cited in over 105 publications since 1961.]

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"During the late-1950s, there was significant activity at RCA Laboratories aimed at the development of tunnel diodes, varactor diodes, and drift transistors. In the course of this work, led by C.W. Mueller, we found ourselves using capacitance measurements to estimate the areas of etched junction structures based on an educated guess about the doping levels in the device structures. At about that time, Boonton Instruments made available a very precise capacitance measurement tool (at 1 MHz) with which three or four significant figures could be obtained for high Q capacitances. With this tool we sought to reverse our previous procedures. By measuring the junction area approximately and the capacitance/voltage variations very precisely, we sought to evaluate the impurity profile within the diode. With these precise capacitance-voltage (C-V) measurements we found that we were able to get the derivative, $d(1/c^2)/dV$, with sufficient accuracy to evaluate the impurity profile. Hilibrand was leaving RCA Laboratories at the time to join the RCA semiconductor activity in Somerville, New Jersey, and we both wanted to report rapidly on what we saw as a useful technique for device designers and process technologists. The theoretical underpinnings in the article came from Hilibrand's course in semiconductor electronics for electrical engineers then offered in the evening session at the City College of New York Graduate School of Technology.

"Several years after the paper was published, D.R. Decker[1] at Bell Laboratories in Allentown, Pennsylvania, reported to the materials community on the evaluation of epitaxial layer doping density vs. depth using this technique. At the same time, J.A. Copeland[2,3] at Bell Laboratories in Murray Hill, New Jersey, reported the development of an instrument that automatically varied the voltage across a junction diode and performed the differentiation electronically so that a graphical display was generated showing the impurity profile. This instrument was soon made available commercially with the result that the C-V technique became widely used. It appears that many of those who used the instrument continued to cite our article, resulting in the extensive citation history. A popular text by A. Grove[4] published in the late-1960s cited our article for C-V measurement to evaluate impurity profiles.

"Both of the authors have moved away from the measurements and instrumentation field but are pleased by the continued usefulness of their work."

1. **Decker D R.** Measurement of epitaxial doping density vs. depth. *J. Electrochem. Soc.* **115**:1085-9, 1968.
2. **Copeland J A.** *CIP: a new technique for measuring doping profiles.* Unpublished paper presented at the International Electron Devices Meeting, 23 October 1968, Washington, DC.
3. ----------------. A technique for directly plotting the inverse doping profile of semiconductor wafers. *IEEE Trans. Electron Devices* **ED-16**:445-9, 1969.
4. **Grove A.** *Physics and technology of semiconductor devices.* New York: Wiley, 1967. 366 p.

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