CC/NUMBER 45
NOVEMBER 6, 1989

This Week's Citation Classic®

Verhoeven J D. Electrotransport in metals. *Metall. Rev.* 8:311-68. 1963.
[Department of Metallurgy, Iowa State University, Ames, IA]

The paper presents a review of electrotransport in solid and liquid metals and solid semiconductors. Electrotransport, more often called electromigration, is a mechanism of mass transport at the atomic level. Although most of the current is carried by electrons in metallic conductors a small transport of the parent atoms occurs, termed electrotransport here. [The *SCI*® indicates that this paper has been cited in over 85 publications.]

Electromigration—When Current Carries Atoms

John D. Verhoeven
Department of Materials Science
and Engineering
and
Ames Laboratory
Iowa State University
Ames, IA 50011

September 12, 1989

This paper was a product of my PhD research work, which was done at the University of Michigan in the Department of Metallurgical Engineering in the time period of 1958 to 1962. I was working under the direction of Dr. E.E. Hucke, Ed to his students, on a problem of electrotransport in liquid metals. I was encouraged by Ed to do a scholarly study and so decided to do a thorough literature survey of the phenomenon. A considerable amount of work was being done in the USSR, and I was able to have this work translated where needed and could, therefore, include the Russian work, which was not widely recognized in the English literature. After coming to Iowa State University and writing a journal paper on the experimental work of my thesis, I realized that the literature review in the thesis might be worthy of publication after suitable modification. This led to eventual publication in *Metallurgical Reviews*.

At the time electrotransport was an obscure phenomenon studied by only a handful of people throughout the world, but that was to soon change. Aluminum films are used in transistor devices as an interconnector material. Because the films are very thin, the surface-to-volume ratio is orders of magnitude higher than in the Cu wires used for most conventional electrical interconnections. Consequently, it is possible to utilize much higher current densities in the Al films without having them heat up because the high surface-to-volume ratio produces a high heat transfer rate and provides much more cooling.

In pure metals electrotransport produces a net flow of the metal atoms due to the momentum exchange with the electric current. The atoms move by jumping into the vacancies in the metal lattice and, consequently, a net vacancy flux is produced. At end points where the current density drops, the vacancies will tend to pile up. Eventually, a void will nucleate and grow. When this happens a hot spot will result because now the current flows through a smaller area and the current density rises causing increased localized heating.

In the early 1960s, there were efforts being made to increase the power densities of transistor devices, and problems were being encountered with failure of the Al interconnects. When it was realized that the mechanism of failure involved electrotransport of the metal matrix atoms, a large interest developed in the phenomenon of electrotransport (electromigration). This, of course, led to the strong interest in my review paper. To illustrate the current interest in this problem, a search was done of journal papers in *Chemical Abstracts*, from 1987 to June 1989, having the word *electromigration* in their title. A total of 68 papers were found related to this problem, and two review papers from this group are listed here.[1,2]

[Editor's note: Our own search of the *SCI* database for January 1987-June 1989, using *SCISEARCH*® on *DIALOG*, found 117 papers with *electromigration* in the title.]

1. **Ho P S & Kwok T.** Electromigration in metals. *Rep. Progr. Phys.* 52:301-48. 1989.
2. **Krumbein S J.** Metallic electromigration phenomena. *Electr. Contacts* 33:15-26. 1987.

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