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404•894•3444

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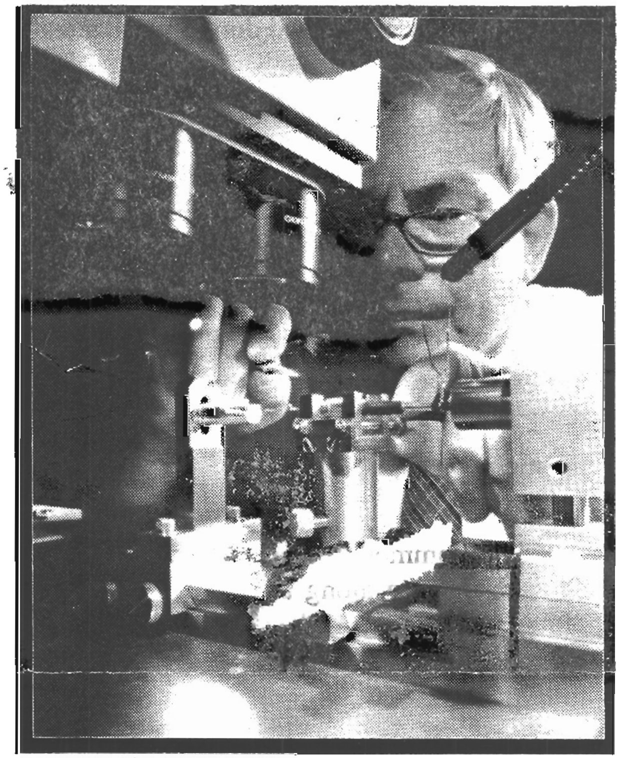
WHAT'S GOING ON INSIDE YOUR COMPUTER? HILLS AND VALLEYS GROW AS ATOMS TRAVEL -- CAUSING FAILURE IN MICROCIRCUITS

Don't look now, but strange things may be happening deep within your computer's microcircuits, as atomic-scale hills and valleys grow in the thin metal conductors used to carry electronic information.

Known as solid state electromigration, this microscopic construction activity causes premature failure in electronic devices. As circuit designers shrink the size of electronic components to crowd more and more of them onto chips, electromigration becomes an increasingly important concern.

"When even a small electric current is run through these minuscule metal conductors, high current densities are built up within their narrow confines," explained Dr. Bill Livesay, principal research scientist in the Georgia Tech Research Institute (GTRI) and a participant in Georgia Tech's Manufacturing Research Center. "This causes atoms within the metal films to move out of place or migrate, causing degradation and ultimate failure of the device."



Dr. Bill Livesay places a section of metal film into a microtensile device to study the effects of electromigration. The work is being done in the Manufacturing Research Center. (Color/B&W Avail.)

Movement of the atoms creates voids in the extremely thin metal film, which can be less than a micron wide -- or about 1/50th the diameter of a human hair. These voids coalesce and increase in size, reducing the amount of conductor left to carry electrical current. In turn, that further increases the current density, accelerating the growth of the void until the current density becomes so large that the remaining conductor melts -- and the device fails.

FOR MORE INFORMATION:

***ASSISTANCE/PHOTO:** John Toon or Lea McLees, (404) 894-3444*
***RESEARCHER:** Dr. Bill Livesay, (404) 894-3489*

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The atoms displaced from the voids cause problems of their own as they migrate through the metal film and stack up as tiny hillocks or even long thin whiskers. These growths can eventually pierce insulating layers in the circuits, causing shorts or other problems.

To help learn how to minimize failures caused by electromigration, a team of scientists headed by Livesay -- and including N.E. Donlin of the U.S. Army's Missile Command (MICOM), along with A.K. Garrison, H.M. Harris and J.L. Hubbard of GTRI -- is using powerful electron microscopy techniques to study the growth of these hills and voids. Based on their research, Livesay and colleagues believe atoms are displaced by electromigration in much the same way they are moved during mechanical deformation.

Mechanical deformation normally occurs when malleable metals like aluminum, copper, gold and silver are stretched, bent, or hammered. The process causes enormous displacement of the atoms through activation of dislocation dynamics.

Electromigration causes similar atomic displacement as high current density moves the atoms around in thin films, which in electronic devices are primarily aluminum. This similarity led Livesay to undertake laboratory tests to confirm the correlation between electromigration and dislocation mechanisms.

"The common supposition was that the atoms were moving along the grain boundaries of the metal," Livesay said. "This does happen, but we felt this was not the primary cause of electromigration. The activation of dislocation dynamics is a far more effective mechanism for the significant atomic displacements taking place during electromigration."

Gathering evidence to show that dislocations are a major factor in electromigration required some atomic-scale detective work.

"We applied high-density current pulses to thin aluminum films while under mechanical stress to see if they caused the material to plastically deform," Livesay explained. "If the dislocation mechanism was operating, the layers would be built up by a rotational effect, creating each whisker as a single crystal. We verified in the electron microscope that this was the case."

An additional piece of evidence from a transmission electron microscope clinched the case.

"If dislocations truly were involved in electromigration damage, we should be able to directly observe this phenomenon in the transmission electron microscope," Livesay continued. "We laid down thin aluminum films and thin single crystals of aluminum. Then we saw the dislocations move during the high-current pulses."

Additional confirmation came from a group of Russian scientists who observed a similar phenomenon in a copper crystal. Other scientists detected acoustical pulses from the hillocks as they grew, suggesting that dislocation was taking place.

Armed with this improved understanding of the mechanisms involved in electromigration, Livesay and other electronic reliability specialists hope to devise the best materials combinations to minimize the problem.

Their suggestions are familiar to materials engineers who already know how to strengthen metals in large-scale use: special alloys and construction of multiple-layer structures to increase the strength of the metallic films.

Understanding the problem of electromigration is an important step toward improving the reliability of the electronic circuits which have become so crucial to today's world. Livesay hopes the techniques developed in this study will help future research.

"In the next decade," he predicted, "these capabilities will be applied to a wide range of electronic reliability problems in the evaluation of new materials combinations to enhance the manufacturability and durability of microelectronic systems."

Livesay presented the results of this research to the IEEE International Reliability Physics Symposium in April 1992. The research was sponsored by the U.S. Army Missile Command (MICOM) in Huntsville, Alabama.

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