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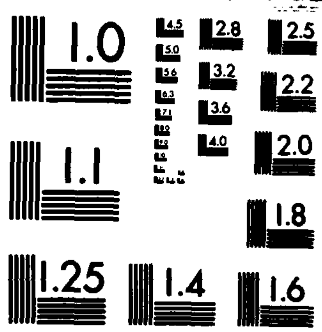

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18. SUPPLEMENTARY NOTES

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Electrotransport; Thin Films; Metallization; Reliability; Microelectronic Circuits; Thermotransport; Grain Boundary Grooving.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Circuit failure in thin film metallizations may be due to a combination of electrotransport, thermotransport and grain boundary grooving. In cases where electrotransport and thermotransport are relatively slow, such as in gold, grain boundary grooving may eventually cause void formation and failure of a microelectronic device. Film combinations consisting of substrate/indium/gold significantly retard grain growth, thermal grooving and hole formation under conditions usually experienced in microelectronic circuits.

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20. (continued)

It is believed that indium oxide near the grain boundaries and on the surface is responsible for the stabilization of the gold grain structure and the prevention of hole formation. Keywords:

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Electrotransport in Thin Films

Final Report

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April 1985

U. S. Army Research Office

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The objective of the research performed under this contract was to develop a scientific perspective that forms a foundation for understanding the processes that lead to the development of holes in thin film metal strips. This understanding leads to an ability to predict, control and prevent hole formation in thin film connectors that are an integral part of all microelectronic devices, thus extending their design lifetime, and improving their reliability.

The research focused upon the effects of addition of second components on the behavior of thin films subjected to high current densities, and upon the relative contributions of the several mass transport processes that may contribute to changes in the structure of thin film strips. Specifically, in addition to electrotransport, which may involve both electron wind and electrolysis effects, grain boundary grooving, driven by surface tension forces, and thermotransport, driven by temperature gradients, have been found to significantly alter the structure of a strip that is subjected to current stressing. Experimental strategies have been developed which emphasize each of these contributions, permitting assessment of their relative roles in the overall process. The research systematically investigated specific solvent-solute combinations selected from the periodic table to provide an overview of the part played by electron structure in processes that lead to the formation of holes.

One of the major findings during the contracted research period was a qualitative understanding of the failure mechanisms which occur in thin film metallizations used in microelectronic circuits. We recognize that the description of these failures should include at least five different mechanisms which may operate simultaneously and influence the formation of holes in various degrees. These failure mechanisms are:

1. Electrotransport (mass flow induced by an applied electric field due to momentum exchange of the intense flux of electrons with the metal ions).
2. Coulomb attraction (mass flow induced by the electrostatic attraction of charged ions to the electrode of opposite charge).
3. Thermotransport (mass flow caused by a temperature gradient).
4. Grain boundary grooving (localized hole formation induced by capillarity forces at grain boundaries).
5. Diffusion (flow of components caused by a concentration gradient).

All failure phenomena which have been observed in the past may be explained by considering the interplay of these mechanisms. For example, it is now possible to answer the long-standing puzzling question why, upon DC current stressing, gold films deposited on silicon wafers fail near the cathode, while similar films under similar conditions on soda-lime silica glass fail near the anode. Our studies using Auger electron spectroscopy clearly indicated that alkali ions which diffuse from the soda-lime silica substrate into the gold film are transported by the electron wind to the anode and there enhance grain boundary grooving, thus accelerating failure. In contrast, in "pure" gold films (i.e., films deposited on quartz) the voids form near the cathode and are mainly introduced by the electro- and thermotransport of the gold ions.

Aluminum interconnections in microelectronic devices have a fairly complex metallurgy which has been developed to increase the lifetime of these devices. Despite the considerable improvements made in the past decade, aluminum metallizations are still riddled by electromigration failures which hamper further miniaturization and reduction in line width to 1 μm.

Gold interconnections could be the answer. Gold metallizations have a longer lifetime under DC stressing. In other words, electromigration failures in pure gold films are less of a problem. This might be attributed to the difference in activation energy for electromigration (and grain boundary diffusion) which is more than 25% higher in gold than in aluminum.

In the course of our research efforts it became evident that indeed thin gold interconnections in microelectronic devices possess longer lifetimes than aluminum metallizations. However, failure eventually occurred even in gold films, mainly by thermal grooving.

In our subsequent investigations we found that an indium underlayer sandwiched between the gold film and the substrate prevented thermal grooving and produced a fine grain structure in the gold under conditions normally expected in service.

Auger studies showed that indium diffuses very readily into gold films (even at room temperature) and that indium oxide forms on the surface as well as within the gold film. No indium oxide was found in the gold films after annealing in hydrogen. It is believed that the driving force for the indium migration through the gold films derives from the formation of indium oxide at the free surface. Since diffusion paths for the indium in gold are predominantly the grain boundaries at these temperatures, it is likely that the observed indium oxide is mainly formed at the grain boundaries.

Our experimental results are consistent with the hypothesis that indium oxide near the grain boundaries on the surface is responsible for the stabilization of the gold grain structure, the prevention of grain boundary grooving and hole formation during thermal annealing, and for the increased lifetime of gold/indium metallizations during current stressing.

List of Individuals Supported with Funds from the Contract

Dr. Rolf E. Hummel, Professor, Co-Principal Investigator

Dr. R. T. DeHoff, Professor, Co-Principal Investigator

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* "New Insights on the Reversal of the Site of Electromigration Failure in Gold Films Doped with Alkali," J. Appl. Phys. 54 (5), (1983), 2855.

* "Electrotransport in Thin Films," University of Alabama in Birmingham, Departments of Materials Engineering and Electrical Engineering, November 3, 1982.

* "Reliability of Microelectronic Circuits," Auburn University, Department of Electrical Engineering, November 5, 1982.

* "Electromigration, Thermotransport and Thermal Grooving in Thin Film Conductors," Proceedings of the 2nd IBM Electromigration Symposium held August 31, 1983 at Poughkeepsie, NY.

* "The Role of Thermal Grooving, Thermotransport and Electrotransport on the Failure of Thin Film Metallizations," Proceedings of the 22nd International Reliability Physics Symposium, Las Vegas, Nevada, April 2-6, 1984.

* "Electromigration and Thermal Grooving in Au/In Films," Proceedings of the 166th Meeting of the Electrochemical Society Symposium of Electromigration, New Orleans, October 1984.

Degrees Awarded during Contract Period

Susan Matts Goho. Dissertation Title: "The Electromigration and Temperature-induced Structural Behavior of Gold Thin Films based upon Alkali Additions" December 1983.

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