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

The formation of holes in gold metallizations during thermal annealing can be prevented by thin indium or tin underlayers. Pulsed electromigration prolongs the lifetime of metallizations. This increase in lifetime is dependent on frequency and duty cycle. Aluminum films deposited by the ionized cluster beam tenique have a substantially longer resistance against electromigration compared to conventionally deposited Aluminum films.

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Reliability of Gold Thin Film Conductors for Microelectronic Applications

Final Report

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and

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May 1989

U. S. Army Research Office

DAAG29-85-K-0100

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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 stripes. 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.

A variety of failure mechanisms operating in a variety of components conspire to determine the reliability of microelectronic devices. One of the most common forms of failure may be traced to the formation of open circuits resulting from the development of holes in thin film connectors in the chip.

Because these circuit elements are thin polycrystalline metallic stripes that are subject to an applied field, a high current density, heat generation and flow, and to temperature gradients, the causes that may lead to hole formation are numerous. Those causes that have been identified include:

1) Electrotransport - "electron wind" (derived from the high current densities attained in operation) transports matter in the direction of the electron flow. The flow is localized at grain boundaries at operating temperatures. Thus, holes form at triple lines in the grain boundary network.

2) Thermotransport - Significant temperature gradients (that develop during device operation) produce mass flow patterns with divergences that lead to hole formation.

3) Grain Boundary Grooving - Capillarity effects operating at the intersections of triple lines (grain edges) with the film surface, cause mass transport that results in migration of such intersections to the substrate surface, forming holes in the film.

The research conducted in the past contract period focused on three main areas.

1) The effects of various metallic underlayers on the stability of thin gold films during isothermal annealing. This study was necessitated because of the observation that gold thin film metallizations, which have a superior electromigration resistance compared to aluminum, still could develop porosity during thermal annealing. We found that different metallic underlays, sandwiched between SiO_2 "substrate" and gold metallizations have different effects on the stability of these gold films. The most encouraging finding was that thin underlayers of indium or tin substantially aid in the stabilization of the grain structure of gold when heated in an oxidizing atmosphere such as air. The indium or the tin from the underlayer migrates during annealing

through the gold film (via grain boundaries) and forms a passivating film of In_2O_3 or SnO_2 respectively on the face surface. These metallic oxides also form in near the grain boundaries thus further aiding in the stabilization of the grain structure.

In contrast to this, thin films of copper and nickel, or traces of sodium were found to aggravate the hole formation of gold films during annealing.

Finally, thin underlays of vanadium or titanium aided in the formation of hillocks on the free surface of the gold metallization.

We acquired a good understanding of why different additions to gold influence the stability of gold films in different ways. We have published on this in refereed scientific journals as listed below.

2) The second thrust of our work was aimed towards pulsed electromigration. Electromigration in thin film metallizations under unidirectional pulsed conditions is of considerable interest to the electronics industry because this mode of operation describes more realistically the maximum stress conditions during operation of microelectronic devices. We developed a model for this case incorporating partial back streaming of the electromigrated ions during off-times. We demonstrated through limited experiments utilizing one pulse frequency (10 KHz) and various duty cycles that our engineering equation fits our experimental findings quite well. The pertinent results were published recently in the Journal of Applied Physics, see below.

3) The third research activity was centered around electromigration investigations of aluminum films deposited by a method which is called the ionized cluster beam (ICB) technique. Even though the interpretation of the technique is controversial, the films still have remarkable properties. We found that ICB deposited aluminum films have a substantially increased electromigration resistance compared to conventionally deposited aluminum films. Indeed, the activation energy for electromigration is about twice as much for the ICB films which translates into a median failure time increase of several orders of magnitude. Again, our results are contained in the open literature, see below.

All taken, we have had a productive research period in which substantially new insights into electromigration mechanisms as well as technical improvements have been obtained. We are greatful to ARO for their moral and financial support which contributed greatly to our success.

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

Soo Young Lee, Graduate Research Assistant

Jin Young Kim, Graduate Research Assistant

David Malone, Graduate Research Assistant

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