THE EFFECTS OF PREMETALIZATION CLEAN ON ELECTROMIGRATION IN Al-Si THIN FILMS ON SiO2 AND POLYSILICON SUBSTRATES.

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ABSTRACT

The effects of premetalization cleaning on electromigration in Al-Si thin films was studied. Premetalization cleaning, divided into a standard RCA clean, DC glow discharge plasma clean, and no clean, were performed on oxide and polysilicon substrates. Test structures were subjected to high current densities of 10e6 A/cm2 and monitored for changes in current resulting from electromigration induced defects. The test station employed in this experiment was subject to current losses which the software erroneously interpreted as electromigration failures, thus completing the test.

INTRODUCTION

Reliability of metal interconnects continues to become increasingly important as metal line cross sections shrink and the total length of interconnects increases. Electromigration, one of several transport phenomena that occur in solids, is the most significant failure mode in interconnect technology for microcircuits where current densities exceed 10e6 A/cm2 without catastrophic failures such as melting. Electromigration is the mass transport of metal ions under the driving force of a high current density [1]. In a current carrying solid, at a uniform temperature, the metal ions are subjected to two driving forces as shown in Figure 1.

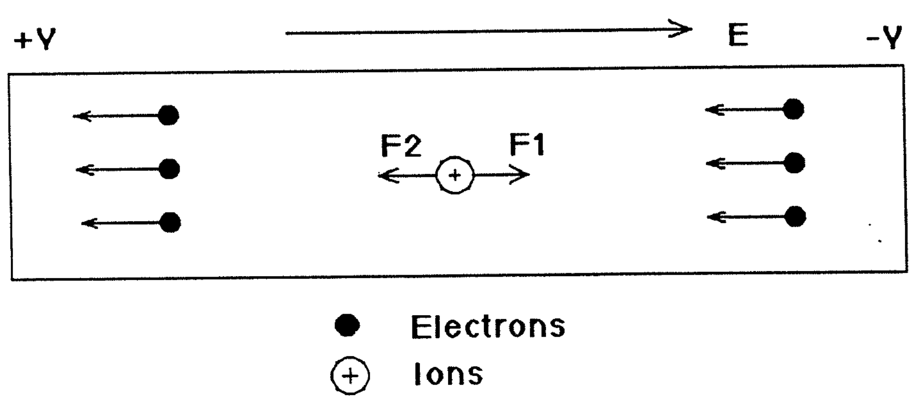

Figure 1: Forces acting on a metal ion during current transport.

Force F1 is the electrostatic force, due to the applied electric field, and is in the direction of the electric field. The second force is the electron wind frictional force which, due to the momentum exchange between conduction electrons and the metal ions, and is in the direction of electron flow [2]. The direction of migration of ions is determined by the relative magnitudes of the two forces. In general, the second force is the more dominant resulting in mass movement in the direction of electron flow. Theoretically, no problems arise since the metal is moved simultaneously, but minor variations in mobility along the conductor cause the metal to be moved at different rates, resulting in void formation, creating an open circuit, or the piling up of metal, creating shorts to adjacent lines.

Variations in structure, geometry, and composition contribute to flux divergencies, which effect the electromigration resistance of interconnects. Metal interconnects are polycrystalline in nature so that diffusion occurs primarily via grain boundaries. The grain boundaries are agglomeration sites for impurities which diffuse from the metal or the underlying substrate during subsequent annealing steps. A typical method of increasing interconnect lifetime is alloying the aluminum with copper and/or silicon. The addition of small amounts of either copper or silicon (i.e. 1-4 wt%) will increase the grain size of the film. The increased grain size increases the activation energy for migration which in turn increases the interconnect lifetime. Final passivation has also shown to increase interconnect lifetimes by inhibiting mobility at the grain boundaries [3].

Alkali metals were shown to decrease the lifetime of gold films [4]. A gold film was deposited onto an alkali oxide then annealed. The alkali metal rapidly diffused from the substrate to the gold grain boundaries. Under current stressing, the alkali metal had a higher mobility than the gold and accelerated void formation in the film. This project focuses on cleaning steps as a source of impurities and their effects on electromigration.

The test station used for electromigration testing utilized the hardware interface board developed by Helen Merz [5]. The interface board allows software control of a power supply and multimeter. The electromigration test held a fixed voltage across the probes and monitored the resulting current. A modified version of the structure developed by Thompson and Cho was used[6]. Their structure had a high volume of line that could be tested in a single test for a rapid statistical analysis. But due to limitations in test equipment, a high current density could not be obtained. Figure 2 shows the modified test structure. The structure consists of five 5 um lines and spaces connected by two contact pads. The structure developed by Thompson and Cho involved 50 lines. The use of this structure would require multiple testing to ensure valid data.

Figure 2: Test Structure

The test circuit held a fixed voltage across the probes and monitored the current. As each line fails, the resistance of the structure will increase, thereby decreasing the current, which maintains a constant current density through each line. The current density can be calculated by the total initial current divided by the number of lines and the cross sectional area, thickness times line width.

EXPERIMENT

Samples for electromigration were made using twelve 3" wafers. An RCA clean was performed on all wafers. A thermal oxide was grown for 30 minutes at 1100C in steam for a thickness of 3500A. Half the wafers had 5500A of polysilicon deposited by LPCVD. Next, the wafers were split into three groups with each group containing 2 oxide and 2 polysilicon substrates. The first group received the standard RCA clean, group 2 received a 10 minute plasma clean in argon and group 3 received no clean prior to metallization. The Al-Si alloy was deposited by evaporation with a resulting thickness of 3900A. All wafers were then coated with KTI820 resist, patterned using using the GCA4800 g-line stepper, developed in KTI ZX934 developer, wet etched in aluminum etch, then annealed at 450C for 20 minutes in forming gas.

Current stressing at 10e6 A/cm2 was done on the test station shown in Figure 3. The Thermochuck system was used to heat the wafer to 200C. A simple custom computer program was developed for testing and is included in Appendix A. The program controlled the Keithley voltage source, the digital multimeter, and the switching matrix. Communication between the equipment utilized the Hewlett Packard Interface Bus, HPIB. A constant voltage was applied across the probes so that a current density of 10e6 A/cm2 was obtained. The current was monitored at specific intervals of time. Current vs time data was sent to the VAX system via KERMIT.

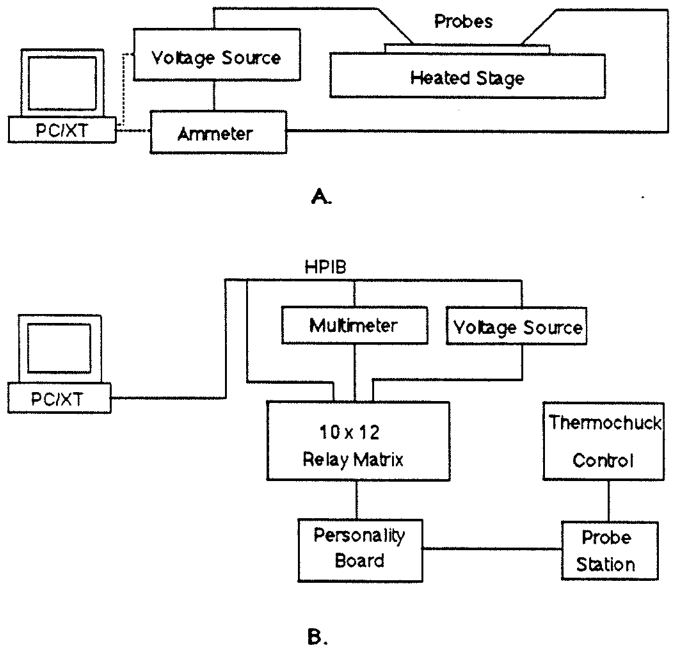

Figure 3: A) Test Circuit, B) Test System

RESULTS/DISCUSSION

Both pure Al and the Al alloy appeared hazy after anneal. Optical microscopy indicated the presence of hillocks in the film. Because the films appeared abnormally rough, it was decided to etch off the Al and redeposit. Interdiffusion between the polysilicon and the aluminum alloy created a thin film which wasn't removed in the aluminum etch. The result was to scrap the polysilicon wafers and begin again.

The newly deposited alloy was evaporated at a slower rate to allow the film to relax. This film showed the same haze after anneal. Testing was started regardless of this problem. The structure was designed as five 5 um lines 1 mm in length. The resulting lines were approximately 2 um from the wet etch process. A current density of 10e6 was applied to the test structure. The program control sampled the current in 10 second intervals.

Problems which arose during testing were probe slippage, causing the current to go to zero completing the test, and high resistance through the test circuit, requiring a higher voltage for the correct current density. After 36 hours of stressing, no evidence of electromigration induced failure was noticed. A senior project done by David Lam studied electromigration of pure aluminum films [7]. There, the mean time for electromigration induced failure for pure aluminum on flat oxide substrate was 5.4 hours. The alloy in the present study will increase the electromigration resistance. Other studies required anywhere from several hours to several months for failure to occur. A more stable test system, utilizing a probe card is recommended due to the length of time required.

CONCLUSIONS

Quality of Al deposition needs to be checked. Evaporation rate, anneal temperature and time should be investigated as the cause of the hillock formation. The computer test program also needs to be improved to allow for probe slippage or the use of a probe card to prevent probe slippage should be developed.

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