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Titanium/Gold Process Characterization

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Allied-Signal Aerospace Company
Kansas City Division

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Topical Report
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Allied-Signal Aerospace Company

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TITANIUM/GOLD PROCESS CHARACTERIZATION

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Prepared by L. S. Fajardo

Characterization of the titanium/gold (Ti/Au) deposition process used at the Allied-Signal Inc., Albuquerque Microelectronics Operation (AMO) was performed. Tests were conducted to set up evaporation parameters, correlate titanium and gold thicknesses to sheet resistance, improve thickness uniformity, and reduce frontside contamination of deposit material on product wafers. The Ti/Au process is the final step in the production of integrated circuits (ICs) at the AMO wafer fabrication facility.

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SUMMARY

Parameters for the Ti/Au deposition process were optimized. These parameters include vacuum integrity, planetary rotation of wafers, current and voltage requirements of the evaporation source, and deposition monitoring. A method was developed for measurement of both titanium and gold thicknesses and correlated to in situ thickness measurement equipment. Using surface analysis techniques, frontside contamination of ICs during the Ti/Au deposit step was detected. Protective backing plates were designed, manufactured, and placed to eliminate the contamination without damage to the wafer fronts. With modifications to system tooling, thickness uniformity was greatly improved.

DISCUSSION

SCOPE AND PURPOSE

Ti/Au deposition, the final process in the production of semiconductor devices, was characterized. Wafers at this step have integrated circuits on the wafer fronts and are bare silicon on the wafer backs. Gold is required on the wafer backs to provide a connection of the completed device to a gold package. Gold, however, will not adhere well to the oxide that forms on the silicon wafer. This step requires the use of a titanium layer, which will adhere well to the silicon wafer. The gold is then deposited and has good adhesion to the titanium layer. Characterization of this process required experiments on both titanium and gold deposition. Deposition parameters for each metal had to be optimized, metal thicknesses had to be determined, and deposition of material in undesired areas had to be eliminated.

PRIOR WORK

Previous Ti/Au process setups on this evaporator were performed by Sandia National Laboratories.

ACTIVITY

Evaporation Process Description

Ti/Au processing is done in a Varian VI-460 evaporator. Wafers to be processed are loaded on half-moon stainless steel fixtures called "planets" and secured to the planets by spring clips. The fixtures are called planets because when they are placed in the system and rotated, the wafers mounted on the planets are rotated in a planetary-type motion above the Ti/Au source. Backs of the wafers are placed facing the source to receive the evaporant material, attempting to avoid deposition on the wafer fronts. Three planets fitted in the system can hold a maximum of 18 wafers per deposition run.

The evaporator chamber consists of a stainless steel bell jar pumped to rough vacuum of 100 mtorr by a Leybold D-60 mechanical roughing pump and then to high vacuum of 2×10^{-6} torr by a Varian eight-inch cryopump. A liquid nitrogen cold trap is used to aid the cryopump in pumping out water vapor. Liquid nitrogen flow is controlled by a liquid level sensor which operates a solenoid valve in the liquid nitrogen line. Ultimate pressure of the VI-460 evaporator is 2.2×10^{-8} torr.

The Ti/Au source consists of tungsten evaporation boats resistively heated to provide a vapor of the desired evaporant material which originally is in pellet form. Power to the boats is provided by a CHA DC power supply. During ramp-up of the power supply and initial melting of the evaporant, the wafers are shielded from the source by a pneumatically controlled shutter. When the evaporant is fully melted, the shutter is opened and the evaporant is projected outward from the source in a line of sight towards the rotating wafers. The process is monitored and controlled by an Inficon IC-6000 deposition controller. Standard processing calls for 500 Å of titanium followed by 2500 Å of gold. After evaporation is complete, the bell jar is vented to atmospheric pressure with dry nitrogen, and wafers are unloaded.

Vacuum Characterization

Characterization of the vacuum integrity consisted of leak-up rate plots and helium leak checking. A leak-up rate plot for the VI-460 is shown in Figure 1. After an initial steepness of the curve, the leveling off is characteristic of a good vacuum system. Helium leak checking with a Leybold UL-100 leak detector verified this with no detectable leaks to the maximum sensitivity of the leak detector of 1×10^{-9} mbar/L/s.

Power Supply Parameters

Initial power supply parameters were chosen from vendor recommendations and previous processes used by Sandia National Laboratories. Voltage and current values were chosen to provide sufficient evaporation but were kept low enough to eliminate any erratic spitting of the metal. Deposition rate, measured by the Inficon IC-6000, was 15 Å/s for titanium and 10 Å/s for gold. At a constant power supply setting of 10 volts, current required to obtain the desired deposition rates was 250 A for titanium, and 240 A for gold.

Titanium Thickness Measurements

A method for measuring titanium thickness had to be developed. A Tencor Alpha Step 200 surface profiler provides accurate measurements of steps by passing a stylus from the bottom of a step to the top of the step and calculating the difference.

The first method used to obtain a step to measure was to place a shadow mask with holes over the wafer and deposit titanium. The titanium passes only through the holes in the masks leaving steps from bare wafer to deposited titanium. Because of shadowing, however, this method did not provide a clean enough step for accurate measurements on the Alpha Step 200.

Figure 1. Ti/Au Evaporator Leak Up Rate Plot

The second attempt to obtain a clean step required chemical etching of a step in the deposited titanium. A blanket layer of titanium was deposited on a bare wafer. A strip of tape was placed on the wafer over the titanium, and the wafer was immersed in a 1:9 mixture of hydrofluoric acid and water. After about a minute of agitation in the mixture, the titanium was completely removed down to the silicon wafer. After rinsing, the tape was peeled off, and unetched titanium was left where the tape had been. The step from bare silicon to titanium was clean enough to provide a good step for accurate measurement on the Alpha Step 200.

Wafers were measured on the Alpha Step 200 to verify titanium thickness. Titanium thickness was checked over several runs and averaged approximately 600 Å. A typical plot from the Alpha Step 200 for titanium is shown in Figure 2. Final thickness during deposition is controlled by the IC-6000, which monitors the change in frequency of a crystal placed near the wafers to measure metal thickness as metal is deposited on the crystal. Metal density and a tooling factor entered in the IC-6000 software are used to correlate actual thickness to that measured by the IC-6000. When the desired thickness is reached, the IC-6000 signals the shutter to close, immediately stopping further deposition on the wafers.

Gold Thickness Measurement

Gold thickness also had to be determined using the Tencor Alpha Step 200, again requiring a clean step obtained by chemical etching. Because gold will not stick well to the bare silicon wafer, titanium was deposited, followed by gold. A strip of tape was placed on the wafer over the gold, and the wafer was immersed in a 3:1 mixture of hydrochloric acid and nitric acid. The gold was etched within about one minute down to the titanium layer, which was not affected. After rinsing, the tape was peeled off, leaving a strip of unetched gold which provided a clean step for accurate measurement of the gold thickness.

Wafers were measured to verify gold thickness, which over several runs averaged approximately 2500 Å. An Alpha Step 200 profile for gold is shown in Figure 3. Metal density and a tooling factor are entered in the IC-6000 software to correlate actual thickness to IC-6000 in situ-measured thickness.

Gold Resistivity Correlation

Because it is impractical to use the wet etch process to determine metal thickness every time a process is run, a correlation between metal thickness and sheet resistance was done. Sheet resistance is measured on a Veeco FPP-5000 four-point probe.

Figure 2. Alpha Step 200 Plot of Titanium Step (595 Å)

Figure 3. Alpha Step 200 Plot of Gold Step (2515 Å)

The bulk resistivity of deposited gold is determined by multiplying the measured thickness by the measured sheet resistance. For the 2500-Å films, sheet resistance values were averaging approximately 125 milliohms/square. Multiplying these two values gives a bulk resistivity of 3.125 microhm-centimeters. Whenever a run is done, the sheet resistance is divided into the bulk resistivity to get an approximate thickness. This correlation is linear, and the bulk resistivity is fairly constant over time, making it a reliable method of determining approximate gold thicknesses.

Uniformity

Metal thickness uniformity across a wafer was measured over several runs and averaged approximately 8%. Because tooling supporting unused quartz heaters was partially blocking the line of sight path of the metal vapor to the wafers, heaters and tooling were removed, and distance from the source to the wafer was maintained. Thickness uniformity was improved to approximately 2% across a wafer.

Adhesion

The only method used for checking adhesion of the gold film was a simple cellophane tape pull test. Adhesion of the gold film was always acceptable when a layer of titanium was underneath the gold. When very little (< 100 Å) or no titanium was deposited, the gold would lift with the tape. With no titanium, adhesion was so bad that all the gold film could be scraped off easily. This allowed reworks if the titanium was not deposited because of operator or machine error.

Contamination

Experiments to verify a concern that evaporant materials were reaching the fronts of the wafers (device side) were performed. Gold is not desired on the fronts of the wafers because it could easily diffuse into the surface when exposed to high temperatures and change the operating characteristics of the device. Tests were performed to measure contaminant levels on a standard unprotected wafer front, and a backing plate protected wafer front.

Low energy ion scattering spectrometry (LEISS) was used by Sandia National Laboratories to measure the amounts of titanium and/or gold on the wafer fronts. LEISS was used because of its superior surface sensitivity and low detection limit for gold (0.01 atomic percent). On the standard unprotected wafer front, titanium and gold were detected at concentrations of 6 and 1 atomic percent, respectively.

Backing plates were designed, manufactured, and welded to the planets to protect wafer fronts. The backing plates were recessed to within 1/16 inch from the edge so that devices on the wafer fronts would not be scratched by the backing plate. Using the backing plate, titanium concentration was reduced to a level below the LEISS detection limit ($<0.5\%$), and gold concentration was reduced to 0.1 percent on the edges of the wafer and below the LEISS detection limit ($<0.01\%$) in the device areas.

ACCOMPLISHMENTS

The major benefit of this project was identifying contamination of the wafer fronts and reducing contamination to a minimum level. Contamination of wafer fronts was not expected. Improvement of thickness uniformity was also a major accomplishment. Uniform film thickness will help in process stability of attachment of the device to the package. Better uniformity and removal of frontside contamination should have a positive effect on device yields and performance consistency of integrated circuit devices.

FUTURE WORK

Future work necessary should be limited to monitoring of vacuum integrity, thickness uniformity, and average thickness. Vacuum integrity will be monitored by a preventative maintenance procedure, and thickness values will be monitored by use of process control measurements.

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