IC 칩 패키지용 PECVD 실리콘 질화막에 관한 연구

A Study on PECVD Silicon Nitride Thin Films for IC Chip Packaging

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Abstract

Mechanical properties of Plasma-Enhanced Chemical Vapor Deposited (PECVD) silicon nitride thin film was studied to determine the feasibility of the film as a passivation layer over the aluminum bonding areas of integrated circuit chips. Ultimate strain of the films in thicknesses of about 5 kÅ was measured using four-point bending method. The ultimate strain of these films was constant at about 0.2% regardless of residual stress. Intrinsic and residual stresses of these films were measured and compared with thermal shock and cycling test results. Comparison of the results showed that more tensile films were more susceptible to crack-induced failure.

1. Introduction

Corrosion of aluminium metallization is by far the leading failure mechanism of integrated circuits in both molded plastic and hermetic packages.[1-2] Microscopic amounts of chloride, phosphoric acid or organic acids, together with water, can interrupt the electrical continuity of interconnect lines and bondpads. Corrosive contaminants are ubiquitous in the manufacturing and operating environment so their presence on an integrated circuit is almost impossible to avoid.[3] Over the coming years, ICs will become much more sensitive to contamination-induced failures than they are now because of the increase in the number of interconnect and the decrease in the wall thickness of packages.

There is currently no effective passivation method for bondpads, bondwires and bond interfaces in commercial usage.[4] Polymeric films such as silicones and polyimides exhibit good mechanical properties, but are relatively poor diffusion barrier. Silicon nitride films are excellent diffusion barrier against water and aggressive ions which might corrode aluminium metallization in packaged microelectronic assemblies. However, films are often stressed and prone to cracking during thermal cycling when used to coat bulk aluminium structures, because of wide mismatch of thermal expansion coefficient (CTE) between them. Tensile stress exceeding the ultimate strain of the film produces cracks.

The purpose of this research was to investigate the failure mechanism of the silicon nitride thin film associated with its mechanical properties. In order to do this, ultimate strain of the films was measured using four-point bending technique. Also, thermal shock and cycling test was employed to investigate how residual stress of the film was related to the mechanical failure due to cracking caused by thermal stress.

2. Experimental

2.1 Test Articles

ATC-01 CERDIP test chip was used to simulate IC chip in commercial usage. Stainless steel 304 strip (90mm x 20 mm x 0.9 mm) was used as a substrate for the silicon nitride thin film. To remove pinhole-induced defective films, the surface was polished with 0.05 micron slurry. Longitudinal and transverse scanning measurements using Dektak 3030 surface profilometer indicated an average roughnesses of about 0.03 and 0.05 μm, respectively. These values were about 10 times less than the thickness of the film used in this experiment, and thus, was considered to be smooth enough not to produce defective films by occasional peak on its surface.

2.2 Deposition of Silicon Nitride Thin Film

Silicon nitride films were deposited using Texas Instrument A-24 Reinberg-style, radial flow, parallel plate reactor. Silane (SiH_4) and ammonia (NH_3) gases were flowed into the reactor and reacted to form silicon nitride under rf electric field. Helium was used to dilute the silane gas for safety. Deposition variables are rf power, substrate temperature, pressure, input gas flowrate, and gas ratio (NH_3/SiH_4). Film thickness was measured with a Gaertner L116B Auto Gain Ellipsometer.

2.3 Thermal Shock and Cycling Test

PECVD silicon nitride thin films over ATC-01 CERDIP Chip and stainless steel strip were subjected to temperature cycling and shock in order to simulate typical industrial temperature stress testing. First, test articles were immersed in -65°C solution (acetone with dry ice) for 10 minutes. Then, they were transferred to 150°C solution (ethylene glycol) and immersed there for 10 minutes. This procedure was repeated 10 times and transfer time was less than 10 seconds. After the test, the articles were examined with microscope in order to find any cracking that might have occurred.

To determine the degree of cracking, 0.5 volt potentiostat was applied to the stainless steel strip with silicon nitride film after the thermal shock and cycling test. While part of the articles were immersed in 0.5M NaCl solution, corrosion current through the cracks on the film was measured with time using an EG&G Princeton Applied Research 363 Potentiometer. Platinum electrode was used as a counter electrode.

2.4 Residual Stress Measurement

To measure the residual strain and stress of the silicon nitride thin film, 2 inch diameter silicon wafer was used. Curvature difference of the silicon wafer before and after deposition was measured using the surface profilometer. This measured value of curvature difference was used to calculate the residual stress of the film. In addition, intrinsic stress of the film was calculated from the residual stress.

2.5 Ultimate Strain Measurement

An apparatus was designed for measuring ultimate strain of the silicon nitride thin films. A schematic diagram is shown in Figure 1.

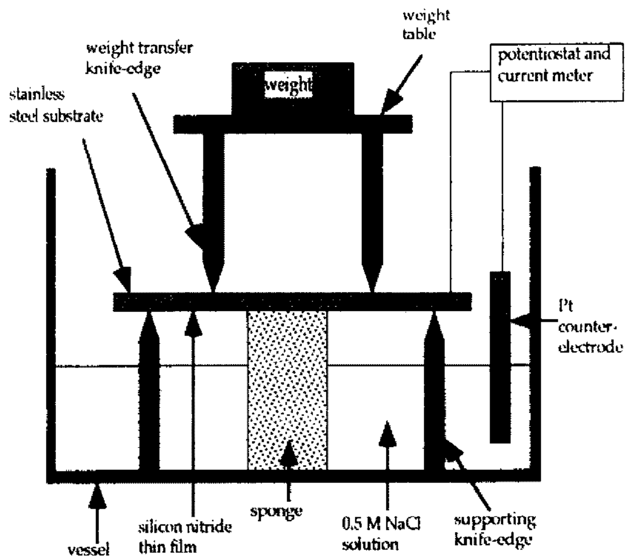

Figure 1. Apparatus For Measuring Ultimate Strain of Thin Films.

One side of the stainless steel strip with film was placed over two parallel knife-edge supports and two other parallel knife-edges which was connected to the weight table was placed over the other side of the strip. Forces were applied to the strip by adding weight over the weight table. Gradual increase in weight finally made crack occur on the silicon nitride thin film because of tensile stress.

As shown in Figure 1, Pt cathode electrode was immersed in 0.5 M NaCl solution. The silicon nitride thin film surface was contacted by a sponge of which bottom part is immersed in NaCl solution and thus soaked up to the silicon nitride surface. The stainless steel strip was made the anode. Therefore, applied controlled potentiostatic voltage drop across the electrodes lead to current flow through the crack to the stainless steel substrate when crack occurred on the film. When current started to flow, the forces applied was recorded at the instant and used for the calculation of the ultimate strain of the film.

3. Results and Discussion

3.1 Ultimate Strain and Residual Stress of Silicon Nitride Thin Film

Silicon nitride thin films were obtaind under four different deposition conditions. The deposition conditions are summarized in Table 1. Density of the films were about 2.5 g/cm^3 and refractive indices were about 1.8.

As shown in Figure 2, residual stress of the film on condition #4 was the most compressive among others. Intrinsic stresses of the films except that on condition #4 were tensile. However, residual stresses of the films were all compressive. This is because residual stress is the stress of the film at room temperature.

Ultimate strain of the films were constant at about 0.2% for all films regardless of intrinsic stress.

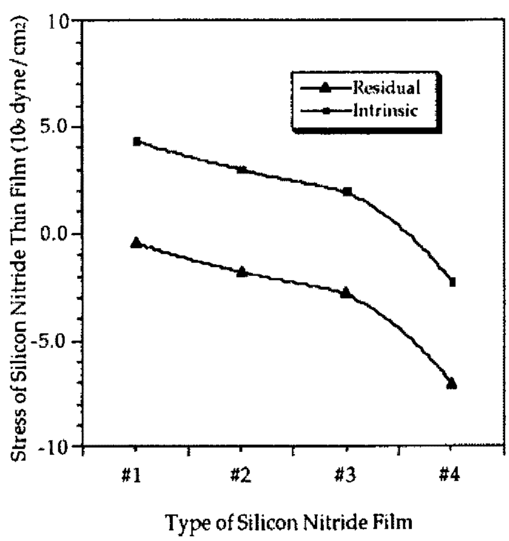

Figure 2. Residual and Intrinsic Stresses of Silicon Nitride Thin Film

Table 1. Deposition Conditions for PECVD Silicon Nitride Thin Films

	Condition #1	Condition #2	Condition #3	Condition #4
Temperature (°C)	300	300	300	300
rf power (watts)	100	100	100	100
Ratio of SiH_4/NH_3	1/4	1/4	1/3	1/3
SiH_4 flowrate (sccm)	24	24	24	24
NH_3 flowrate (sccm)	96	96	72	72
Pressure (torr)	2.0	0.5	2.0	0.5
Deposition rate (Å/min)	262	52	213	52
Thickness of silicon wafer (cm)	0.03048	0.02794	0.032512	0.032258
Film thickness (cm)	0.00005632	0.00005122	0.00005116	0.00005761

3.2 Resistance to Cracking due to Thermal Stress

Thermal shock and cycling test was conducted to investigate the resistance to cracking according to film's intrinsic and residual stress. While the film side of the substrate was contacted with 0.5 M NaCl solution, 0.5 volt potentiostat was applied across the substrate. Then, corrosion current through the cracks to the substrate was measured with time.

As shown in Figure 3, amount of corrosion current was maximum with stainless steel strip without film. For the film on condition #4, almost no corrosion current flowed. When these results were compared with the residual stress of the films in Figure 2, it was found that more corrosion current was detected with more tensile film. Consequently, more tensile films were more susceptible to cracking due to thermal stress.

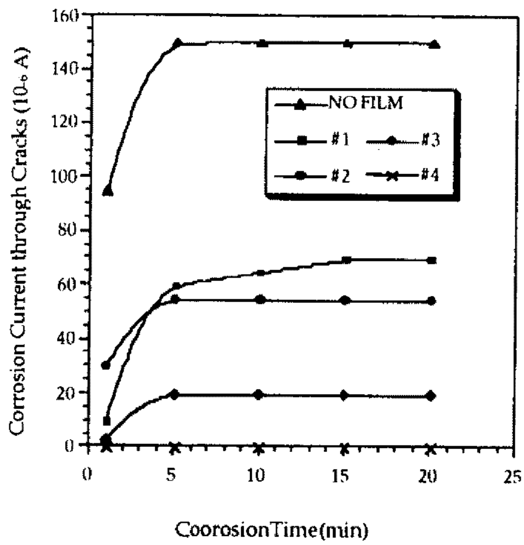

Figure 3. Corrosion Current through Cracks after Thermal Shock and Cycling Test

Number of cracked bondpads of CERDIP chips after the thermal shock and cycling test were counted using a microscope. Figure 4 shows that the number of cracked bondpads decreased with increased compressive stress. This result also indicated that more tensile films were subjected to severer cracking during thermal shock and cycling test.

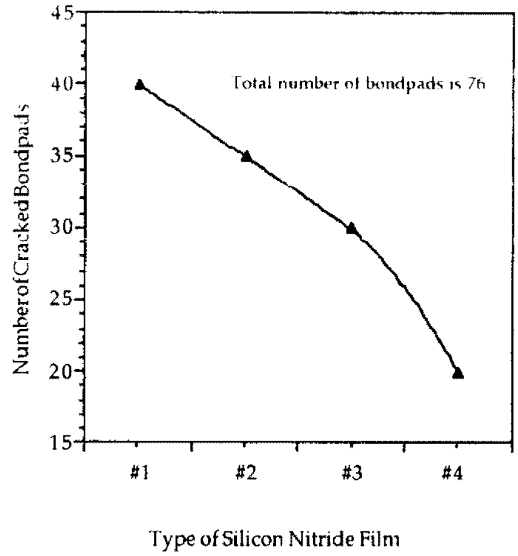

Figure 4. Number of Cracked Bondpads on CERDIP after Thermal Shock and Cycling Test

4. Conclusion

Ultimate strain of the silicon nitride thin film could be successfully measured using the designed apparatus. The ultimate strain of the silicon nitride films was constant at about 0.2% regardless of their residual stress. However, thermal shock and cycling test results indicated that film's resistance to cracking due to thermal stress increased as the film's residual stress became compressive. Consequently, compressive PECVD silicon nitride thin film can be considered to be a potential protective film over the aluminum bonding areas in microelectronic assemblies.

References

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