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Mechanical characterization of low-*k* and barrier dielectric thin films

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Abstract

The integration of low-*k* organo-silicate glass interlayer dielectrics is accompanied by an increase in mechanical reliability risks. New characterization techniques must be developed, particularly for measuring thermo-mechanical properties. This paper presents and compares the use of two mechanical characterization techniques: Brillouin light scattering technique and nano-indentation, for determining Young's modulus, Poisson's ratio and hardness of low-*k* films and dielectric barrier layers. The obtained values of the elastic constants are then used to evaluate the coefficient of thermal expansion from substrate curvature measurement during thermal cycling. The low-*k* film studied is a carbon-doped silicon oxide (SiOC:H, $k = 3.0$) and the dielectric barrier is an hydrogenated nitrogen silicon carbide film (SiCN:H, $k = 5.0$), both deposited by plasma enhanced chemical vapor deposition (PECVD).

Keywords: Low-*k* dielectric; Mechanical properties; Elastic modulus; Poisson's ratio; Coefficient of thermal expansion

1. Introduction

The introduction of low-*k* dielectric materials in ultra-large scale integrated (ULSI) circuits enables a reduction in resistance–capacitance (RC) delay and crosstalk [1]. Fig. 1 shows a TEM cross-section of a six-level metal circuit made with low-*k* dielectric and 65 nm node design rules [2]. However mechanical properties of this new class of materials are weaker than those of traditional silicate glass films [3]. Reliability failures can occur when mechanical or thermal stresses

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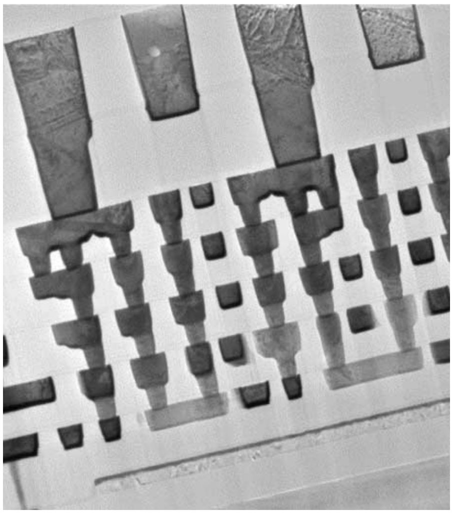

Fig. 1. TEM cross-section of a six-level metal circuit made with low-k dielectric.

are introduced during the manufacturing process or packaging. Stress-induced voiding and electromigration are two important intrinsic reliability concerns for copper interconnects. Moreover, when the interconnect is exposed to temperature cycling, stress changes due to the different thermal expansion coefficients of the various layers can also cause delamination and cracking [4,5].

As such, it is also important to determine the mechanical properties of low-k films. Several techniques such as nano-indentation, surface Brillouin light scattering (BLS), ellipsometric porosimetry, dual-substrate bending beam technique or micro-tensile testing of free-standing films [6–8] have already been used to determine elastic and plastic properties of thin films, including elastic modulus.

In this study, two characterization methods have been employed and compared in order to measure Young's modulus, Poisson's ratio and hardness: BLS and nano-indentation. The results were then used to evaluate the in-plane thermal expansion coefficient from substrate curvature measurement during thermal cycling. Measurements were completed on an organo-silicate low-k film and on a carbide-based dielectric barrier. The dielectric barrier serves to prevent the diffusion of the copper from the underlying metal trench into the overlying low-k layer and also provides an etch stop during fabrication.

2. Experimental details

The films have been deposited by plasma enhanced chemical vapor deposition (PECVD) on a silicon substrate. The low-k film ($k = 3$) is a carbon doped silicon oxide (SiOC:H) deposited at 350 °C, from trimethylsilane (3MS) and oxygen precursors. The barrier layer is a hydrogenated nitrogen silicon carbide film (SiCN:H) deposited via the direct dissociation of 3MS in helium and ammonia at 350 °C. The film thicknesses were approximately 1 μm for BLS and nano-indentation. However 500 nm SiOC:H and 200 nm SiCN:H were used for curvature measurements.

The film thickness and the refractive index (at 633 nm wavelength) were precisely measured by spectroscopic ellipsometry using a PROMETRIX UV-1280SE from KLATENCOR. The dielectric constant was measured using a Solid State Measurement Mercury Probe CV system (SSM 5100 CV) on the metal–insulator semiconductor (MIS) structure at 0.1 MHz. Finally, the mass density of the films was measured by X-ray reflectivity (XRR) using a JVX 5200 from Jordan Valley. Table 1 presents a summary of these measurements.

3. Brillouin light scattering technique

The BLS technique [9] is a non-destructive tool which allows the elastic characterization of thin films and layered structures. It is based on the inelastic interaction between photons from a monochromatic laser light source with acoustic phonons naturally present in the structure under investigation.

The small frequency shift, f, of the Brillouin peaks due to scattering of the photons is directly related to the phase velocity v of acoustic waves through

Table 1
Values of the refractive index, dielectric constant and mass density of the films investigated

	n	k	ρ (g/cm^3)
SiOC:H	1.44 ± 0.01	3.0 ± 0.1	1.5 ± 0.1
SiCN:H	1.93 ± 0.01	5.0 ± 0.1	1.9 ± 0.1