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Mechanical Strength of Multilayered Dielectric Structures Measured by Laser-Pulse Generated Surface-Acoustic-Wave Technique

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1. Introduction

Laser pulse generated surface acoustic wave (LSAW) technique is known as a powerful nondestructive characterization method applicable even to thin fragile films such as porous low-*k* materials for future ULSI interconnects [1]. In the present work, we report our recent development of the LSAW technique to extend its applicability to measuring mechanical strength of realistic multiple-layered structures that consist of porous low-*k* and insulator films for interconnects. Both theoretical calculation and experimental results are presented to demonstrate the capability of LSAW technique to characterize the mechanical properties of porous low-*k* films embedded in multiple-layered structures. Its application to evaluation of process-induced damages upon overlayer deposition is also discussed.

2. Theoretical calculation of LSAW propagation on layered film structures

Figure 1 shows a schematic model of a three-layered film structure, on which excitation laser pulse and piezoelectric transducer are also shown. Derivation and solutions of coupled wave equations for LSAW propagation from equations of motion for displacement vector in elastic thin film on substrate were reported earlier [1, 2]. For calculating the LSAW propagation in the layered structure shown in Fig. 1, we took into account the boundary conditions at all the interfaces between the dielectric layers, the bottom film and the substrate, and the top film and the ambient air. Frequency dispersion of LSAW phase velocity was obtained by numerically solving the resultant eigenvalue problem [3].

Figures 2 and 3 show examples of thus obtained LSAW dispersion curves for triple-layered structures on Si substrate consisting of a cap insulator, low-*k* and bottom insulator. Properties of each layer assumed in the calculation are summarized in Table I. The calculated dispersion curves for different Young's modulus of low-*k* film are compared in Fig. 2, while those for different low-*k* film thicknesses are in Fig. 3. It has been shown theoretically that the LSAW phase velocity dispersion curve is sensitive to detect subtle change in constituent film properties of low-*k* / insulator layered structures.

3. Experiments

Ultraviolet laser pulses from a nitrogen laser were line-focused onto a film surface to generate broadband SAW wavepackets and were detected by using a piezoelectric transducer as shown in Fig. 1. Amplitude and phase spectra were obtained by a fast Fourier transform analysis of the detected waveform to calculate frequency dispersion of phase-velocity. The details of measurement and analysis procedures are similar to what were used for the experiment on single layer dielectric on substrate, which were reported earlier [1]. We employed ultra-low-*k* porous silica formed using nonionic surfactant [4] as the low-*k* film sample. Figure 4 shows two examples of LSAW phase-velocity dispersion curves deduced from experimental waveforms. The sample structures are shown in the figure. Grazing-incidence X-ray reflectance and spectroscopic ellipsometry analyses were employed to independently determine the densities and thicknesses of the constituent layers, and the results in Fig. 4 were used to determine Young's modulus of the low-*k* films by least-square fitting, as shown in Fig. 5, with the theoretical results.

4. Discussion

The least square fitting (Fig. 5) of the experimental results in Fig. 4 revealed that the Young's moduli of the low-*k* films in the layered structures remained nearly unchanged from those of single-layer of the identical low-*k* film which were also evaluated by LSAW technique. Resolution of the Young's modulus determined from the least square fitting in Fig. 5 is better than 0.1. It suggests that the porous low-*k* bulk layer did not get seriously damaged in terms of Young's modulus during the cap-layer deposition process by plasma-enhanced chemical vapor deposition.

5. Conclusion

We have developed a theoretical calculation program and then experimentally demonstrated the validity of the LSAW analysis technique for low-*k* / insulator multiple-layered film structures. This newly developed technique will open up the way for nondestructive diagnositics of process-induced damages potentially break up during fabrication of multi-stacked low-*k* / Cu interconnects.

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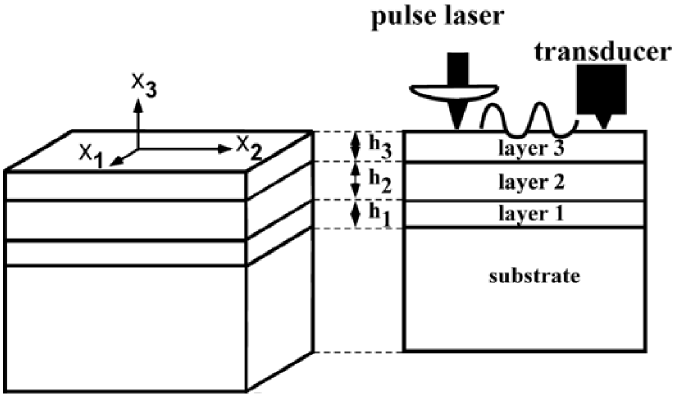

Fig. 1 A model of three layered structure for theoretical calculation and a schematic configuration of SAW generation and detection system.

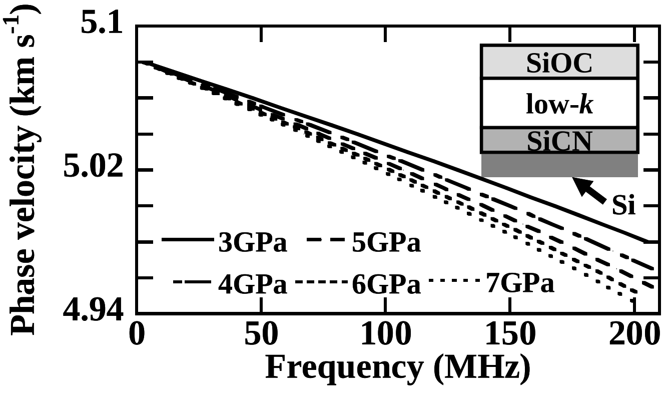

Fig. 2 SAW dispersion curves for different low-*k* film Young’s moduli.

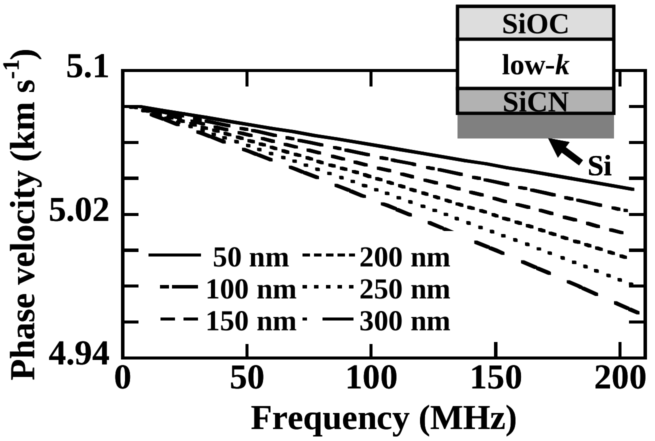

Fig. 3 SAW dispersion curves for different low-*k* film thicknesses.

Table I Parameters of each layer in samples

	Thickness (nm)	Density (g/cm3)	Poisson ratio	Young's modulus(Gpa)
Low-k 1	335	0.88	0.26	3.5
Low-k 2	298.4	0.99	0.23	3.2
SiCN	24.7	1.70	0.29	33.6
SiOC	121.9	1.49	0.37	6.0

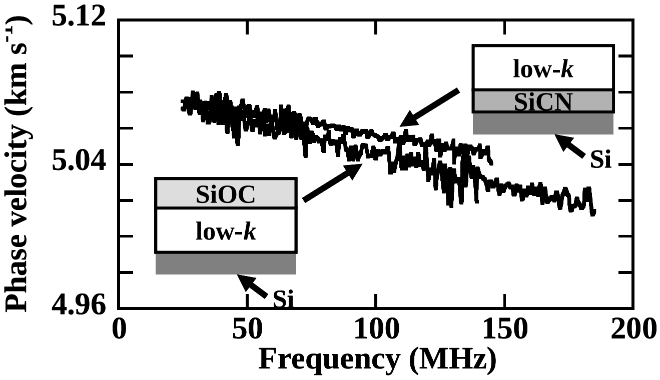

Fig. 4 SAW dispersion curves of experimental data for samples with two layered structures.

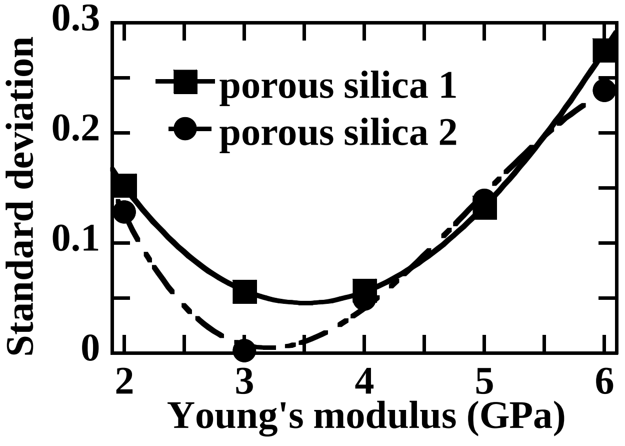

Fig. 5 Young’s modulus determination of porous silica low-*k* films 1 and 2 by least-square fitting to simulation.