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# Nondestructive characterization of dielectric stack structures by laser-pulse-generated surface acoustic wave analysis

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## 1. Introduction

A nondestructive characterization of film mechanical properties by laser-pulse-generated surface acoustic wave (SAW) has been applied to determine Young's modulus and Poisson's ratio in a realistic dielectric stack structure consisting of a cap layer, a low-k film, and an etch-stop layer on $SiO_2$ / Si. Measurements of the stacked structures after pattern etching and resist ashing have also been performed and the results discussed.

## 2. Experimental

The dielectric stack structures composed of CVD-SiOC / porous silica low-k (k = 2.1) / CVD-SiCN on SiO2 / Si substrate were fabricated as shown in Fig. 1. Blanket films of each layer as well as partially-layered structures were also prepared for comparison. Experimental setup for the SAW measurement is schematically shown in Fig. 2. Third harmonics of selected 30 ps light pulses from a mode-locked yttrium-aluminum-garnet (YAG) laser were line-focused onto the specimen to generate SAW. Surface displacement caused by the SAW propagation was detected by a line-shaped piezoelectric transducer at two different distances from the SAW generation line. Density and thickness of each layer were determined by x-ray reflectance and spectroscopic ellipsometry analyses, the results of which are summarized in Table I. Those values were used as input parameters for SAW simulation, in which equation of motion was solved considering the boundary conditions at the interfaces [1]. For the measurements of the patterned samples, three different SAW propagation directions with respect to the trench patterns as shown in Fig. 3 were employed. The signal waveforms were Fourier transformed to obtain frequency dispersion of SAW phase velocity.

## 3. Result and Discussion

Figure 4 shows the experimentally obtained frequency dispersion curves for the blanket films and stacked structures without patterning. Young's modulus ($E$) and Poisson's ratio ($\nu$) of each layer were determined by least-square fitting of simulation curves to the measured results shown in Fig. 4, and the best fitted values of $E$ and $\nu$ are summarized in Table II. It is seen in Table II that the values of $E$ and $\nu$ determined from the blanket films, partially stacked structures and fully stacked structure are consistent with each other. This implies that there was no significant degradation of the film mechanical properties during the formation processes of the stacked structure [2].

The phase velocity dispersion curves obtained from the measurements of the patterned samples are shown in Fig. 5, together with the result from the sample before patterning. No significant difference is observed between the results for the configuration A and B in Fig. 3. The SAW wavelength can be calculated by dividing the phase velocity 5 x $10^3$ m $s^{-1}$ by frequency 100 – 250 MHz to obtain 50 – 20 μm. Because the half pitch of the patterns of 200 nm is more than 2 orders of magnitude smaller than the SAW wavelength, the phase velocity dispersion is not very much sensitive to the pattern shape but rather get affected by the reduction of the average density of the overlayers, which is proportional to the pattern density. This explains the similar results for the configuration A and B, while the configuration C results in the dispersion curve slightly closer to the case of the sample before patterning, in consistency with its lower pattern density than A and B.

It should be mentioned that there are remaining issues to be solved when the number of layers or the interfaces are increased. Namely, the time necessary for simulation explodes, and increased number of material parameters makes it difficult to properly separate them.

## 4. Conclusion

Laser-pulse-generated SAW technique has been employed to analyze dielectric stack structures aiming at low-k / Cu interconnects for 45 – 32 nm technology node. The mechanical properties of the low-k films in the stacked structure remained almost unchanged as in the blanket film, suggesting damages during stack formation is not serious in this case. Analysis of the patterned samples revealed that the pattern density affects the SAW propagation through reduction of average overlayer density.

## Acknowledgements

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## References

[1] T. Takimura et al, SSDM 2005, (2005) 52.
[2] S. Chikaki, et al., Proc. IITC 2005 (2005) 48.

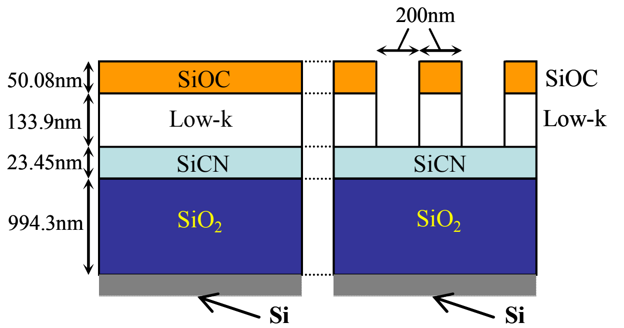


Fig. 1 Schematics of the dielectric stacked samples with and without patterning.

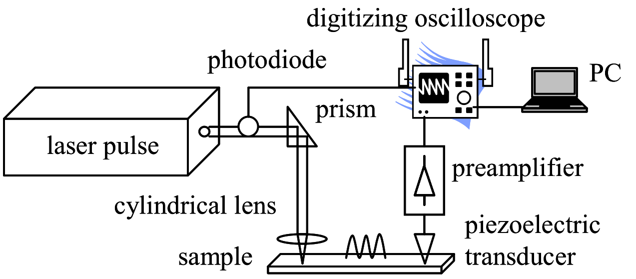


Fig. 2 Experimental setup for the laser-pulse-generated surface acoustic wave analysis.

Table I Density and thickness of each layer in the blanket films and stacked samples

| Sample | Layer | Density (g cm$^{-3}$) | Thickness (nm) |
|---|---|---|---|
| Blanket films | $SiO_2$ | 2.18 | 994.3 |
| | low-k | 0.82 | 133.9 |
| | SiCN | 2 | 23.45 |
| Doubly Stacked-1 | SiCN | 2 | 23.45 |
| | $SiO_2$ | 2.18 | 994.3 |
| Doubly Stacked-2 | low-k | 0.82 | 133.9 |
| | SiCN | 2 | 23.45 |
| Triply Stacked Structure | low-k | 0.82 | 133.9 |
| | SiCN | 2 | 23.45 |
| | $SiO_2$ | 2.18 | 994.3 |
| Fully Stacked Structure | SiOC | 1.355 | 50.08 |
| | low-k | 0.82 | 133.9 |
| | SiCN | 2 | 23.45 |
| | $SiO_2$ | 2.18 | 994.3 |

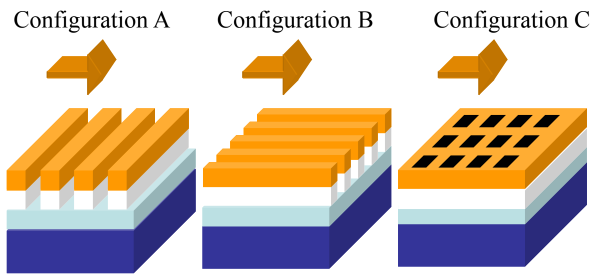


Fig. 3 Configurations of the SAW measurement of the patterned samples. The arrow represents the propagation direction of the SAW.

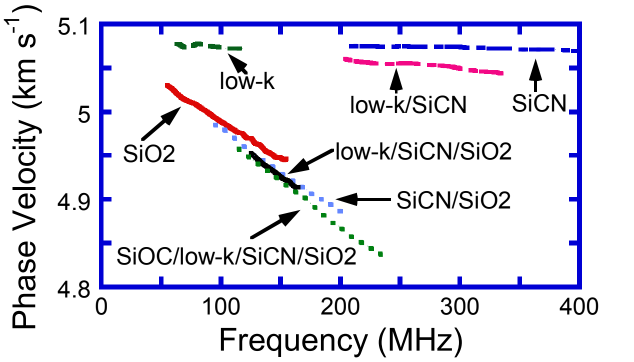


Fig. 4 Experimentally determined frequency dispersion curves of the SAW phase velocities in the blanket film and dielectric stack structure samples without patterns.

Table II Young's modulus and Poisson's ratio of each layer determined from the experimental data shown in Fig. 4.

| Sample | Layer | Young's modulus (GPa) | Poisson ratio |
|---|---|---|---|
| Blanket films | $SiO_2$ | 58.4 ± 1.9 | 0.258 ± 0.005 |
| | low-k | 4.3 ± 1.5 | 0.347 ± 0.001 |
| | SiCN | 29.1 ± 1.9 | 0.314 ± 0.001 |
| Doubly Stacked-1 | SiCN | 29.1 | 0.314 |
| | $SiO_2$ | 56.2 ± 0.3 | 0.267 ± 0.002 |
| Doubly Stacked-2 | low-k | 4.6 ± 1.8 | 0.347 |
| | SiCN | 29.1 | 0.314 |
| Triply Stacked Structure | low-k | 4.3 | 0.347 |
| | SiCN | 29.1 | 0.314 |
| | $SiO_2$ | 58.4 ± 1.8 | 0.258 |
| Fully Stacked Structure | SiOC | 12 | 0.35 |
| | low-k | 4.3 | 0.347 |
| | SiCN | 29.1 | 0.314 |
| | $SiO_2$ | 59.6 ± 0.9 | 0.258 |

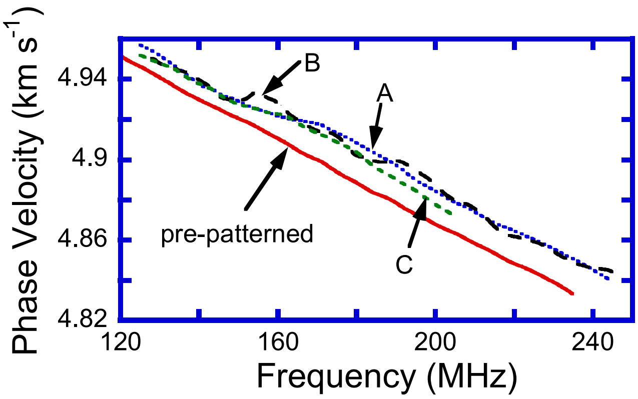


Fig. 5 Frequency dispersion curves of the SAW phase velocities obtained from the patterned samples. The dotted, dashed, and the dash-dotted curves are the results from the measurement configurations A, B, and C in Fig. 3, respectively. The result from the sample without patterning is shown for comparison by the solid curve.