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Acoustic Study of Photoresist Films Applied under Various Conditions

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1. Introduction

Photoresist films are essential to the lithography process, a fundamental process in micro-electromechanical systems, and their physical properties affect the accuracy and stability of the fine-scale structures produced.[1] Among the various physical properties, the hardness of the film is important, so the development of a photoresist with a hardness optimized for micro-patterning performance is being studied.[2]

So far, when sound passes through a thin layer, the transmission and reflection coefficients of sound pressure take extreme values at the resonant frequency. Because this acoustic resonance is highly correlated with the physical properties and thickness of the layer, it has been widely used to characterize layered media, such as a polymer[3] or lubricating film[4], and polymer coating. An acoustic resonant imaging technique has been proposed to visualize the acoustic properties and thickness of a thin film on substrates.[5]

In this paper, the effect of baking temperature after spin coating photoresist film on Si substrates on the acoustic impedance of the film was investigated by the acoustic resonant imaging.

2. Theory

An ultrasonic transmission system shown in **Fig. 1** is considered. A thin film is on the top surface of the substrate (Si wafer). Ultrasound is transmitted into the substrate through the film, and the echo reflected on the backside of the substrate is recorded. The amplitude spectrum of the echo, which is obtained by Fourier transform of the waveform of the echo, is denoted as φ_1. On the other hand, the amplitude spectrum of the echo in the absence of the film is denoted as φ_0. The amplitude ratio, γ, is given by φ_1 / φ_0, and this takes its maximum value, $\gamma_{\max}$, at the resonant frequency. Assuming that a thin film adheres to the substrate and no signal loss in the film due to the ultrasonic attenuation, the acoustic impedance of the film, Z_F, can be determined from $\gamma_{\max}$ as:[3]

$$Z_F = \frac{1}{2}\left(\Gamma - \sqrt{\Gamma^2 - 4Z_W Z_S}\right), \tag{1}$$

And

$$\Gamma = \frac{Z_W + Z_S}{\sqrt{\gamma_{\max}}}, \tag{2}$$

where Z_W (= 1.48 MN m^{-3} s) and Z_S (= 19.64 MN m^{-3} s) are the acoustic impedances of water and Si wafer, respectively.

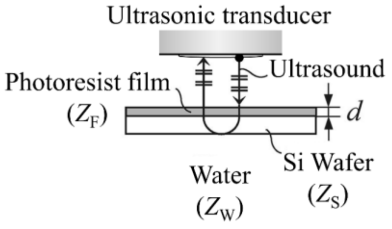

Fig. 1 Ultrasonic transmission system for recording the echo reflected on the back of the Si wafer through photoresist film.

3. Experiments

A positive photoresist (OFPR-800-LB200cp; Tokyo Ohka Kogyo) was used in this study. It was coated on a 0.3-mm-thick Si wafer by using a spin coater at 500 rpm for 5 s and then at 3000 rpm for 20 s. After that, the photoresist film was soft baked on a hot plate at the temperature ranging from 80 to 130ºC) for 7 min. This process was repeated 3 times. Finally, a post-bake at 10ºC higher than that of soft-bake was applied for 30 min on a hotplate to harden the photoresist. The photograph of the sample surface soft-baked at 100ºC is shown in **Fig. 2**(a).

The acoustic image was obtained through the use of an ultrasonic imaging system (FineSAT III, Hitachi) and a focused ultrasonic transducer (V3658, Hitachi). The diameter, focal length, and nominal frequency of the ultrasonic transducer used were 6.4 mm, 12 mm, and 75 MHz, respectively. A frequency analysis of the waveforms stored with ultrasonic image in the visualization toolkit format was performed using Python language to obtain their amplitude spectra in order to construct the $\gamma_{\max}$ image. For more details, please see ref [5].

4. Results and Discussion

Figure 2(b) shows an example of the acoustic image of the sample with the photoresist film baked at 100ºC, and the imaged area corresponds to Fig. 2(a). As shown in the image, the area with film was brighter than that without film, indicating that the intensity of the echo at the positions A and B with film was greater than at the position C without the film. This is due to the difference in the echo transmittance between the water and the Si wafer in the cases with and without the film.

The amplitude spectra of the echoes obtained at A, B and C are shown in Fig. 2(d). The behaviors

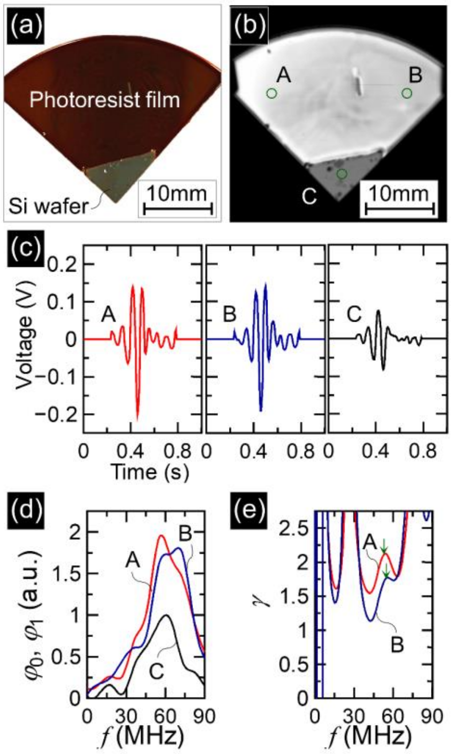

Fig. 2 (a) Photograph of Si wafer with photoresist film baked at 100°C. (b) Acoustic image of the echo reflected at the backside of the wafer, where the film was on the top side. (c) Waveforms at A, B (with film) and C (without film). (d) Amplitude spectra. (e) Amplitude ratio.

of γ at A and B are shown in Fig. 2(e). The values of $\gamma_{\max}$ at A was 2.13 at 53.9 MHz, and that at B was 1.77 at 55.2 MHz, respectively. From the values of $\gamma_{\max}$ and Eqs. (1) and (2), the values of Z_F at A and B were determined to be 2.41 and 2.11 MNm^{-3}s, respectively.

The $\gamma_{\max}$ image obtained by analyzing Fig. 2(b) is shown in **Fig. 3**(a), along with the scale bar of Z_F determined by Eqs. (1) and (2). The values of $\gamma_{\max}$ ranged between 1.24 to 3.04, and those were fluctuated in the image. The values of Z_F on the right side of the image were smaller than those on the left side. The values of Z_F ranged between 1.68 to 3.30 MNm^{-3}s, and the average value of Z_F in all image was determined to be 2.46 ± 0.35 MNm^{-3}s.

The average values of Z_F of all 6 samples, which were obtained from the $\gamma_{\max}$ images similarly to Fig. 3(a), are shown in Fig. 3(b) as a function of the baking temperature. The value of Z_F increased with the temperature, reaching the maximum value at 90°C (2.54 ± 0.20 MNm^{-3}s). And then, Z_F decreased with the temperature. The minimum value of Z_F was obtained at 80°C. At this temperature, the photoresist film is most uniformly heated during the curing process of the film, and therefore, the standard deviation of Z_F became minimal at 80°C.

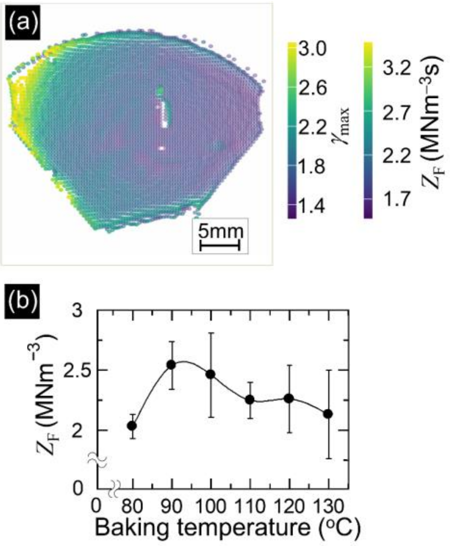

Fig. 3 (a) The $\gamma_{\max}$ image of the photoresist film baked at 100°C together with the scale bar of Z_F. (b) The values of Z_F as the function of the soft-baking temperature.

The acoustic impedance is given by the product of sound velocity and density. Usually, the harder the material, the faster the sound velocity. Thus, the photoresist film baked at 90°C might be the hardest among the 9 films baked at different temperatures.

5. Summary

In this paper, the acoustic impedance of the photoresist films on the Si wafer baked at different temperatures was visualized by the acoustic resonant imaging technique, showing that the acoustic impedance fluctuated. Moreover, it was shown that the acoustic impedance of the photoresist film baked at 90°C was the largest among the films baked in the temperature range of 80°C to 130°C. In other words, photoresist hardness peaks at 90°C, while the hardness decreases with increasing baking temperature.

Acknowledgment

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