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Effect of baking conditions on acoustic properties of photoresist film

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1. Introduction

The lithography process utilized in very large-scale integration (VLSI) devices is highly dependent on the essential function of photoresist films, which play a critical role in enabling pattern formation. In order to achieve maximum efficiency, it is imperative to conduct a comprehensive assessment of the characteristics of the film. The utilization of ultrasound for non-destructive evaluation has emerged as a dependable and trustworthy methodology. Specifically, the phenomenon of acoustic resonance taking place within the thin layer provides valuable insights into the physical properties and thickness of the film. In our recent study, an acoustic resonant imaging technique has been utilized to visually examine the acoustic characteristics and thickness of thin films deposited on substrates.[1)] The primary objective of our previous research was to examine the acoustic impedance of photoresist films on silicon wafers, with varying soft bake temperatures employed.[2)] Nevertheless, it was observed that there was only a limited correlation between soft bake temperatures and density. On the other hand, the influence of the hard bake temperature on the resistance to etching was significant, indicating a more substantial correlation with density.

This study employed an acoustic resonant imaging technique to investigate the impact of different hard baking temperatures and durations on the acoustic impedance of photoresist films that were deposited on silicon substrates. The effect of hard baking temperature and hard baking time after standard fabricating photoresist film on Si substrates on the acoustic impedance of the film was investigated by the acoustic resonant imaging.

2. Theory

In **Fig. 1**, an ultrasonic transmission system involving a Si substrate coated with a thin film, normally transmitted ultrasonic waves experience reflection upon reaching the backside of the substrate. The received echo waveform is subjected to Fourier transform analysis, resulting in the computation of the amplitude spectrum, denoted as φ_1. Similarly, in the absence of the thin film, the amplitude spectrum φ_0 is obtained. At the resonant frequency f_R^S, the amplitude spectrum ratio γ (= φ_1 / φ_0) reaches its maximum value, designated as γ_{max}. The resonant frequency f_R^S is determined by the equation:[3)]

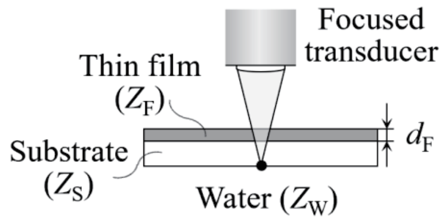

Fig. 1 Ultrasonic transmission system for recording the echo reflected on the back of the Si wafer through the photoresist film.

$$f_R^S = \frac{c_F}{4d_F}, \quad (1)$$

where c_F represents the sound velocity within the thin film, and d_F denotes its thickness. Under the assumptions of negligible ultrasonic attenuation and close adherence of the thin film to the substrate, the acoustic impedance of the thin film Z_F is determined through the following Equations (2) and (3).

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

$$\Gamma = \frac{Z_W + Z_S}{\sqrt{\gamma_{max}}} \quad (3)$$

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

3. Experiments

Acoustic imaging was conducted using an ultrasonic imaging system (FineSAT III, Hitachi) along with a focused ultrasonic transducer (V3658, Hitachi) featuring a diameter of 6.4 mm, a focal length of 12 mm, and a nominal frequency of 75 MHz. The collected waveforms from the ultrasonic images were subjected to frequency analysis in the visualization toolkit format. In each point, a time region of interest corresponding to the backside echoes reflected from the substrate through the thin layer was analyzed using Python to obtain their amplitude spectra, which were then utilized to construct the γ_{max} image. For further details, please refer to reference [1].

The photoresist film was applied to a 2-inch, 0.3 mm-thick Si wafer, divided into quarters, using a

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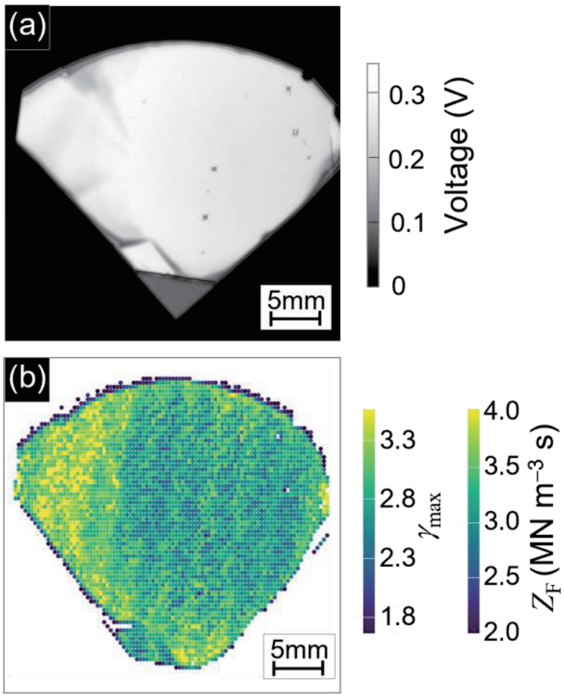

Fig. 2 (a) The acoustic image depicts the echo that is reflected from the backside of the wafer, certainly the area where the film was positioned on the top side. (b) The γ_{max} image of the photoresist film constructed through signal processing (a), along with the scale bar of Z_F.

spin coater at 500 rpm for 5 seconds and then at 3000 rpm for 20 seconds. Afterward, the photoresist film underwent a soft bake process on a hot plate at 110°C for 7 minutes, repeated three times. Subsequently, the focus of this study was on the hard-bake parameter, where the photoresist was hardened at temperatures ranging from 120 to 180°C for 30 minutes on a hotplate. Additionally, the effect of hard bake time was investigated by setting the temperature to 120°C and varying the baking time at 5, 30, 60, and 120 minutes.

4. Results and Discussion

Fig. 2(a) shows the acoustic image of the photoresist film that hard baked at 120°C for 5 min. As shown in the image, the area covered with the film exhibited a higher level of brightness compared to the area without the film. This showing suggests that the intensity of the echo originating from the presence of the film surpassed that of the echo reflected from the absence of the film. The observed variation in echo transmittance between water and the Si wafer can be attributed to the presence or absence of the film. The γ_{max} image obtained by analyzing Fig. 2(a) is shown in Fig. 2(b), along with the scale bar of Z_F determined by Eqs. (2) and (3).

The CART (Classification And Regression Tree) regression model has been chosen for the prediction of Z_F values. The total number of dataset is 40,069, and was split into training and test sets in a 70/30 ratio. For the training set, the coefficient of determination (R-squared) is 57.75%. The R-squared quantifies the proportion of the variance observed in the response variable that can be accounted for by the predictor variables. The Root Mean Squared Error (RMSE) value is 0.3349. The indicator quantifies the mean discrepancy between predicted values and actual values, with smaller values indicating superior performance of the model. The R-squared value for the test set is 57.86%, RMSE is 0.3347, indicating that the model is capable of generalizing to data that it has not been trained on. **Fig. 3** shows the contour image depicting the predicted Z_F obtained through the regression model. It indicates that the influence of the Z_F on the hard baking temperature is more significant compared to the baking time.

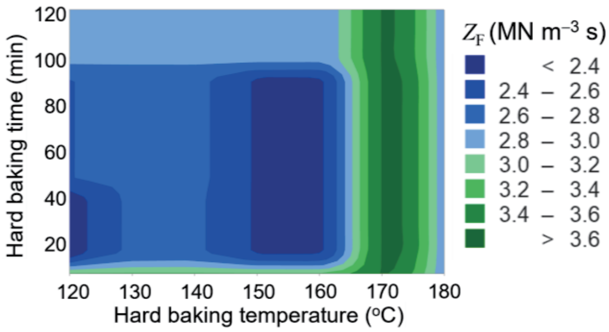

Fig. 3 The contour image of predicted Z_F by plotted on the hard baking temperature-time plane.

5. Summary

This study focuses on the effects of hard baking conditions—temperature and time—on the quality of the photoresist films on Si wafers. The acoustic impedance of the photoresist film was visualized by the acoustic resonant imaging technique, revealing that it fluctuated. Afterwards, the dataset was utilized to construct a regression model. The results of the model were in good accurate representations with measured acoustic impedence of photoresist film.

Acknowledgment

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References

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