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Rotation analysis of the light scattering variation of latent flaws through light scattering measurement with applied stress effect

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Abstract

The stress-induced light scattering method (SILSM) was proposed for inspecting surface to detect polishing induced latent flaws. In this study, in order to clarify the mechanism of the light scattering intensity variation of latent flaws using SILSM, we have investigated stress effect of light scattering intensities using rotation analyzing system. As the results, the mechanism of the change in the light scattering intensity was experimentally proved as change in the mechanical stress effect around latent flaws.

1. Introduction

Fine polishing techniques, such as chemical mechanical polishing (CMP), are indispensable on current key industries such as fine glass substrate for smart phone and dielectric interlayer polishing for high integrated circuit in semiconductor manufacturing[1-6]. In the CMP process, mechanical friction frequently causes cracks in nano- and micro meter order[7]. Recently, many nondestructive inspection systems that use light scattering from foreign matter particles for their detection have been made commercially available for use in production sites[8-10].

For the intense needs from manufacturing industry, we proposed stress-induced light scattering method (SILSM)[11-14] and successfully not only visualized the latent flaws thorough light scattering effect but also distinguished the latent flaw from other light scatterers such as metal lines and tiny particles in cases of a CMP-ed silicon wafer[11] or a polished glass substrate[12-14]. The stress application process was originally composed with expectation of stress concentration at tip of the latent flaws which cause the change in the birefringence and consequently the change in the intensity of light scattering for the selective visualization of the latent flaws through the SILSM. However, in spite of the previous successful demonstration, the mechanism for the selective visualization of the latent flaw have been remaining as speculation as described above, and clarification of the mechanism has been strongly required from the viewpoints of insurance of product quality on latent flaws in manufacturing. Therefore, we have investigated the stress effect using rotation analyzing system.

2. Stress-induced light scattering method

The stress-induced light scattering method (SILSM) is

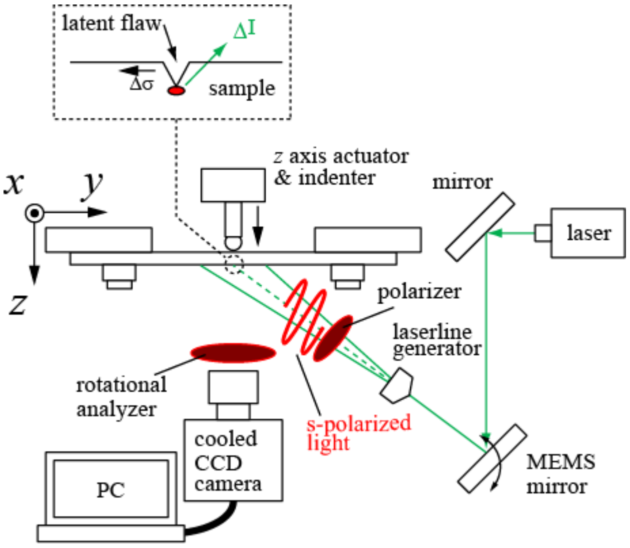

Fig. 1 Experimental system for SILSM with polarization-sensing detectors.

able to distinguish between latent flaws and tiny particles on the fine polished surface[11-14]. Firstly, the light scattering intensity is measured without the mechanical stress applied to the sample. Secondly, the scattering intensity is measured while the stress is applied to the sample. The difference between the first and second scattering measurements is due to the changed refractive index in the vicinity of the latent flaw tip in the sample because of the stress concentration or reduction is caused[15]. The maximum difference is highly dependent on the location of the latent flaw.

When a bending stress is applied to a latent flaw on the sample surface, the refractive index at the tip of the latent flaw is $n+\Delta n$. Thus, the change of the light scattering intensity $|\Delta I_s(\theta)|$ from before to after applying the bending stress, is described by Eq.(1)[11-14].

$$|\Delta I(\theta)| \approx \frac{9\pi^2 I_i (1+\cos^2\theta) V^2}{2\lambda^4 R^2} \left| \frac{4A^2(\sigma^2 + 2\sigma\sigma_r)}{9n^2} \right| \quad (1)$$

I_i, λ, R, n, n_0, θ and V are the incident beam intensity, the wavelength of the incident light, the distance from the scatterer to the observation point, the refractive index of the scatterer, the refractive index around the scatterer, the scat-

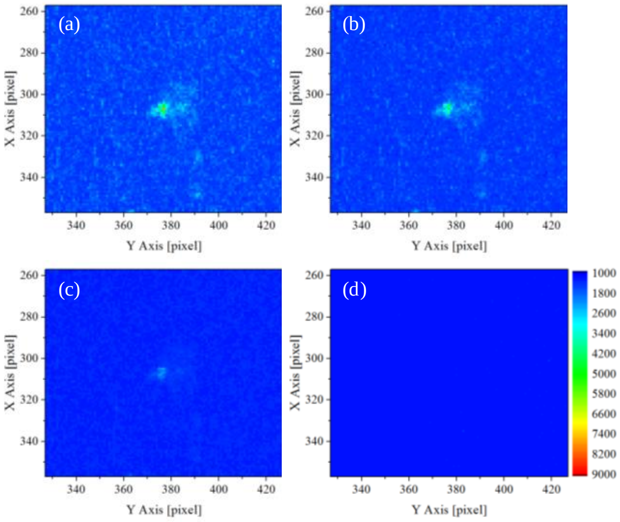

Fig. 2 Light scattering images of a latent flaw captured by cooled CCD camera. (a) $\theta = 0°$. (b) $\theta = 30°$. (c) $\theta = 60°$. (d) $\theta = 90°$.

tering angle with respect to the incident beam direction, and the volume of the scatterer, respectively.

3. Experimental procedure and results

A 120mm × 25mm × 0.65mm glass substrate sample[12-14] was intentionally indented by a Vickers hardness tester. The sample surface was fine polished such that several tens of micrometers of sample were removed from the surface and the resulting sample had only one latent flaw on the surface. Figure 1 shows a schematic overview of the SILSM experimental setup with polarization sensing detectors. The laser source's central wavelength is λ = 532nm. In this experiment, s-polarized light (x axis linear polarized light) was emitted and incident on the glass substrate sample. Incident light scattered by the sample is detected by a cooled charge-coupled device (CCD) camera. To detect the polarization states and reflection coefficients, a rotational analyzer is placed before the object lens of the CCD camera and rotated 90° using an automatic rotating stage. A sample is fixed on an automatic axial stage using clamps (gauge length = 36mm) at both ends. The sample is deformed 150µm along the z axis by indenters. Before and after stress loading, light scattering images of the glass substrate were captured for each orientation of the analyzer by means of a cooled CCD camera.

Figure 2 shows light scattering images at 0°, 30°, 60° and 90° of rotation analyzer angles captured by the cooled CCD camera. The highest light scattering in Fig.2 is due to the latent flaw. Figure 2 shows that the light scattering intensity of the latent flaw decreased according to rotation analyzer angle. Figure 3 show light scattering intensities of the latent flaw each rotation analyzer's angles from 0° to 90° after applying stress. As shown Fig.3, the peak occurred at 40° and it is consider that the polarization state changed depending on applied stress effect.

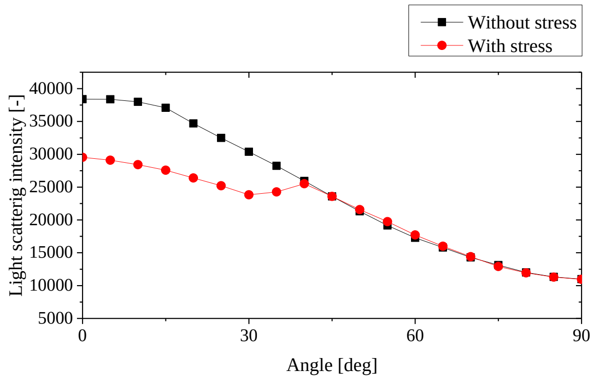

Fig. 3 Change in the light scattering intensities before and after applied stress. The peak occurred around 40° after applied stress.

4. Conclusions

In order to clarify the mechanism of the light scattering intensity variation of latent flaws using SILSM, we have investigated stress effect of light scattering intensities using rotation analyzing system. As the results, it was confirmed that the peak occurred at 40° and it was consider that the polarization state changed depending on applied stress effect.

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