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Evaluation of a SPR Sensor by Sub-Nanosecond Pump-Probe Technique

サブナノ秒ポンプ・プローブ法による SPR センサの性能評価

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1. Introduction

Photoacoustic microscopy (PAM) has attracted increasing attention in high resolution and non-invasive imaging of biological samples[1]. PAM is a technique which enables to obtain images of biological samples from the distribution of light absorbers such as hemoglobin. By irradiating the light absorber with a specific pulse laser, ultrasonic waves are generated due to the photoacoustic effect. These ultrasonic waves are usually measured by an ultrasonic transducer. The absorption coefficient is obtained from the signal intensity. The distribution of light absorbers can be tomographic-imaged from the position of the laser irradiation and the propagation time.

In order to improve the spatial resolution in the depth direction of the PAM imaging, a wide frequency band detector is necessary. However, the present spatial resolution of the PAM is limited by the bandwidth of the ultrasonic transducer. Therefore, for higher spatial resolution, an ultrasonic transducer with a wide band frequency, and working in the high frequency range is required[2].

In recent years, the surface plasmon polarliton resonance (SPR) stress sensor has been reported as a technique with a high-spatial resolution and ultra-flat frequency response[3-5]. The SPR stress sensor is expected to be the future optical detector of the PAM. For this purpose, it is important to evaluate the performance of the SPR stress sensor for the application of a dynamic stress variation such as, ultrasound radiation. In this study, we have focused on the stress induced by the thermo-elastic effect using a sub-nanosecond pump-probe method. The transient stress was generated by the sub-nanosecond pump-probe technique. Then, this transient stress was measured by the thermo-elastic effect of the pump light of the sub-nanosecond pulse for the excitation of ultrasound in the GHz or sub GHz range.

2. Experimental principles

2.1 Sub-nanosecond pump-probe technique

A pump-probe technique is a time-resolved measurement. Here, the photo-thermal transient response of the stress occurs on the sample surface when the pump light is irradiated. The probe light can measure this response as the optical reflectivity changes. The designed system, shown in Fig. 1, is composed of a sub-nanosecond laser (Coherent, Helios 1064-5-50, pulse width : 690 psec). The spot diameter of the probe light was approximately 5 μm. The delay time of the pump light was controlled by 3 round-trips automatic delay line (from 0 to 3 m, which corresponds to 10 nsec) consisted of 5 retroreflectors. The irradiation positions of the pump light and the probe light were adjusted using a microscope (Dejiken, 3R - WM 401 WIFI).

2.2 Surface plasmon polariton resonance (SPR)[6]

The surface plasmon polarliton resonance results from the electromagnetic excitations at the interface between a metal and air. If the incident light is *p*-polarized and the wave number of the incident light coincides with the wave number of the surface plasmon in the in-plane direction, surface plasmon is excited. Then, the reflectance of the light at the metal surface is reduced.

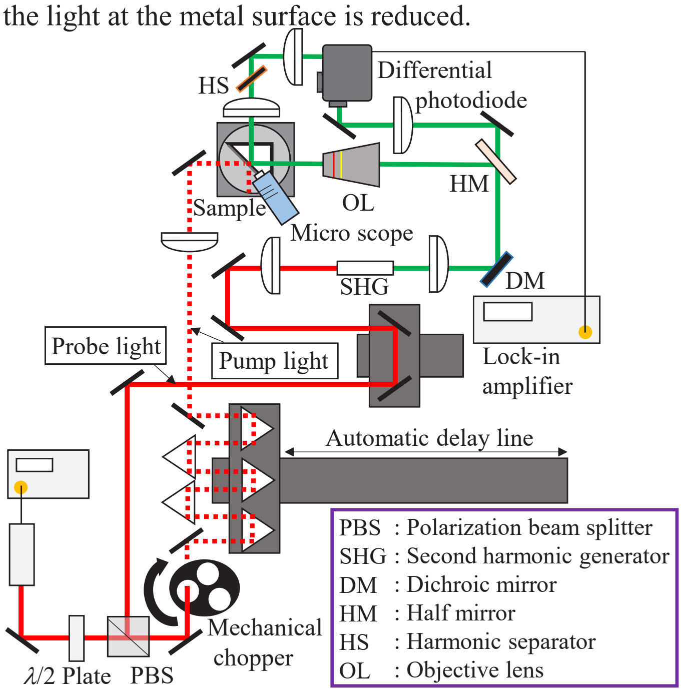

Fig. 1 The developed sub-nanosecond pump probe measurement system.

In this study, a SPR stress sensor with Kretschmann configuration (Fig. 2) is used. The SPR sensor was comprised of an Ag metal film (thickness : 53 nm) on the BK7 glass prism, deposited by an electron-beam deposition apparatus (EB1100, Canon Anelva Corp.). The incident angle of the probe light was set at the SPR angle (46.5º).

3. Results and discussions

The transient signal responses with different intensity of the pump light are shown in Fig. 3. As the intensity of the pump light increased, the intensity of the signal also increased. It indicates that the stress on the sample due to the thermo-elastic effect increases as the intensity of the pump light increases. However, when the intensity of the pump light was 20 μJ, the signal could not be detected. In addition, when the intensity of the pump light was 250 μJ, an ablation occurred around 4.9 nsec, and the intensity of the signal remarkably decreased, then the signal was not detected. On the other hand, when the pump light was 300 μJ, an ablation occurred immediately after the irradiation of the pump light and the signal could not be detected. Actually, the microscopic observation tells us that the Ag metal film on the substrate was peeled off due to the ablation. This caused the vanishment of the surface plasmon. These results show that it is necessary to reconsider configurations of the SPR sensors for better performance of the system.

The peak intensities of the observed signals are shown in Fig. 4. They almost proportionally increased as the pump light increased within the detectable range of a SPR stress sensor. This is reasonable considering the linear relation between the intensity of the pump light and the stress. The SPR stress sensor may effectively detect the stress change due to ultrasonic waves in the GHz or sub GHz range.

4. Summary

A SPR stress sensor was applied to measure the stress induced by the thermo-elastic effect of the pump light. The detected signal increased almost in proportion to the light intensity. The results showed that a SPR stress sensor could detect the stress change of the ultrasonic waves from sub GHz to the GHz range. However, the signal could not be detected when the intensity of the pump light was lower than 20 μJ. Additionally, when the intensity of the pump light was higher than 250 μJ, the ablation occurred and the signal was not detected, accurately. Next step will be the improvement of the sensor configuration and the calibration of the observed signal.

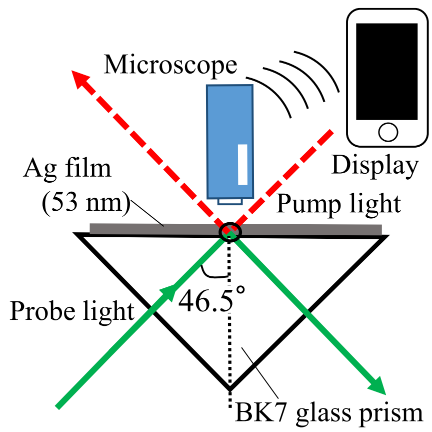

Fig. 2 The fabricated Kretschmann configuration SPR stress sensor.

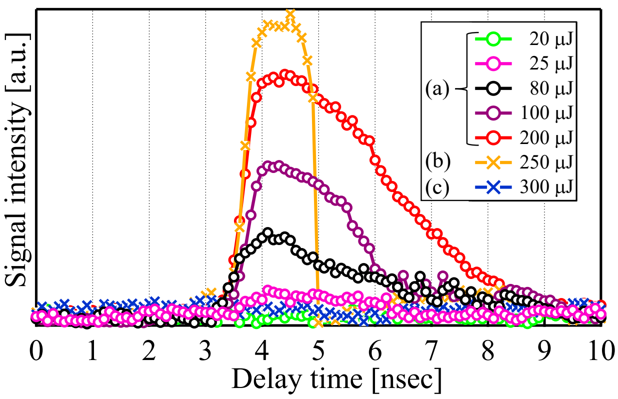

Fig. 3 Transient-thermal responses observed by sub-nanosecond pump-probe technique : (a) non-ablation, (b) ablation (4.9 ns), and (c) ablation (0 ns).

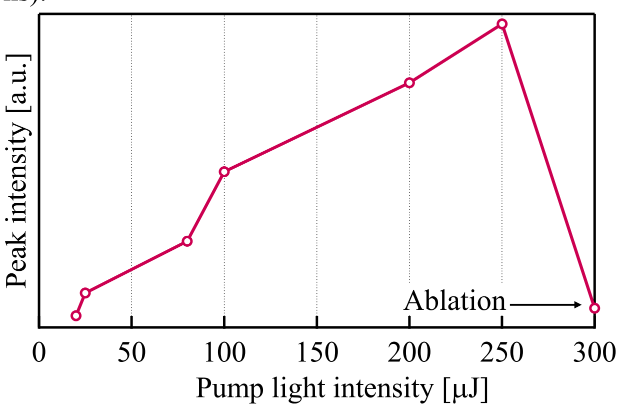

Fig. 4 The peak intensities of transient-thermal responses by changing the intensity of the pump light.

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