3P1-2

Surface plasmon resonance sensor for ultrasound in the MHz range

MHz 帯の超音波検出用表面プラズモン共鳴センサの開発

Shoya Ueno[1†], Hayato Ichihashi [1], Takumi Fukunaga [1]and Mami Matsukawa[1] ([1]Doshisha Univ.)
上野 翔矢 [1†], 市橋 隼人 [1], 福永 拓未 [1], 松川 真美 [1] ([1] 同志社大学)

1. Introduction

Photoacoustic microscopy (PAM) has attracted attention as a high contrast and non-invasive imaging technique for biological samples. PAM enables to obtain images of biological samples from the distribution of light absorbers such as hemoglobin. By irradiating the light absorber with a specific laser pulse, ultrasound waves are generated due to the photoacoustic effect. These ultrasound waves are usually measured by an ultrasound detector. However, the axial resolution of PAM is not suitable for imaging small cells due to narrow frequency band of the transducer. Therefore, for higher resolution in the axial direction, an ultrasonic transducer with a wide frequency band, and working in the high frequency range is required [1].

In recent years, surface plasmon resonance (SPR) sensors have been reported as ideal ultrasonic detectors with wide frequency band and ultra-flat frequency response [2]. SPR sensors detect signals due to the changes in the refractive index near the surface. This sensor is expected to be the future ultrasound detector for PAM. For this purpose, it is important to evaluate the performance of the SPR stress sensor at high frequencies. In this study, ultrasound measurements in the MHz range were experimentally performed using a simple SPR sensor.

2. Surface plasmon resonance (SPR) [3]

The surface plasmon resonance results from the electromagnetic excitations near the metal layer. SPR occurs when the momentum matches between the wave number of the *p*-polarized incident light k_x and the surface plasmon wave k_{sp}. The incident angle of the laser beam should be adjusted to the resonance angle, where k_x matches k_{sp}. This angle depends on the refractive index of the metal layer, prism and external medium. At the resonance angle, the light reflectance at the metal surface is strongly attenuated. If the sound pressure is applied to the metal layer, the resonance angle changes because of the changes in the refractive index of external medium [4-5]. Then, the SPR sensor may detect changes in the reflectance as the signal intensities.

Figure 1 shows the reflectance of the SPR sensor. The signal intensity mainly changes due to the changes in reflectance (ΔR). In this study, gradient of the reflectance became the largest at the incident angle of 73.6°. Then, the SPR sensor was installed at 73.6°.

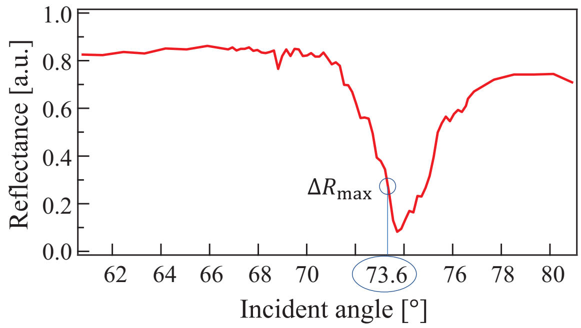

Fig. 1 Reflectance of the SPR sensor as a function of the incident angle.

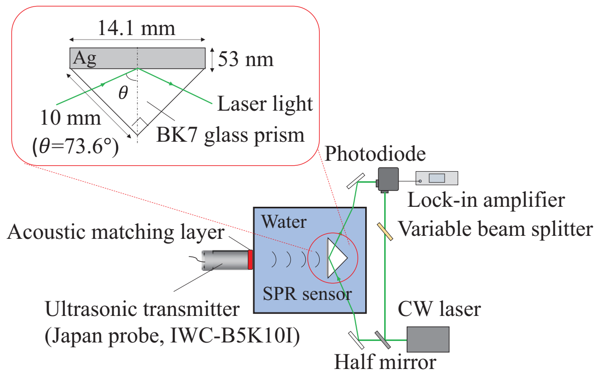

Fig. 2 Sound pressure measurement system used.

3. Ultrasound detection

Figure 2 shows the experimental system. A SPR stress sensor with Kretschmann configuration was used. The sensor was comprised of an Ag metal film (53 nm) on the BK7 glass prism, deposited by an electron-beam deposition apparatus (EB1100, Canon Anelva Corp.). The system was composed of a CW laser (Laser Quantum, mcp-3000, wave length: 532 nm). In the experiments, one cycle of sinusoidal wave (repetition frequency: 1 kHz) with 0 to 20 V at 3, 4 or 5 MHz was applied to the ultrasound transmitter (Japan probe, IWC-B5K10I).

ctud1039@mail4.doshisha.ac.jp

The signals were detected by a lock-in amplifier. Lock-in amplifier multiplies the detection signal and reference signal for 5 seconds.

Figure 3 shows the detected signal intensity by the photo diode. The intensity increased by increasing the pressure of ultrasound. The stronger the sound pressure was, the more refractive index of water near the sensor surface changed, and reflectance also increased. The signal response always showed nonlinear behaviors. Eqs. (1) and (2) indicate changes in reflectance at the SPR sensor (R).

$$R = \left|\frac{r_{12}+r_{23}exp(2ik_{2z}h_2)}{1+r_{12}r_{23}exp(2ik_{2z}h_2)}\right|^2 \qquad (1)$$

(i: Imaginary unit)

$$r_{ab} = \frac{n_a cos\theta_b - n_b cos\theta_a}{n_a cos\theta_b + n_b cos\theta_a} \quad (a, b = 1, 2, 3) \quad (2)$$

where, h_2 , r, k_{2z}, and n indicate the thickness of metal layer, reflection coefficient between media, wave number of the incident light in the thickness direction of the metal layer, and refractive index. Subscripts 1, 2, and 3 indicate prism, metal layer, and water. Eqs. (1) and (2) show nonlinear changes in reflectance, which is similar to the behavior of detected signals.

4. Ultrasound propagation inside of the prism

In this system, we measured signal for a 5 seconds using the lock-in amplifier. Then the measured sound pressure contains reflections from the surface and in the SPR sensor. The precise ultrasound propagation inside the prism should be experimentally investigated.

Figure 4 shows the experimental system. In this experiment, to avoid the interference of ultrasound, a single sinusoidal wave of 70 V at 4 MHz was applied to a PVDF ultrasonic transducer (Focus type, Toray). The reflected waves were observed by the same transducer.

Figure 5 shows the detected reflected waves. ① and ② indicate the reflected waves from the surface and inside the prism. The reflected waves in the prism were observed at the sensor surface. The phase of the first and second reflected wave inside the prism were inverted. It shows that ultrasound reflected twice inside the prism. Reflected waves were clearly separated and little interferences were found.

5. Summary

A SPR sensor was applied to detect the ultrasound in the MHz range. The signal response showed nonlinear behavior to the sound pressure. The SPR sensor has a simple structure without cables, which may be used as the compact and convenient ultrasound detector in the MHz range.

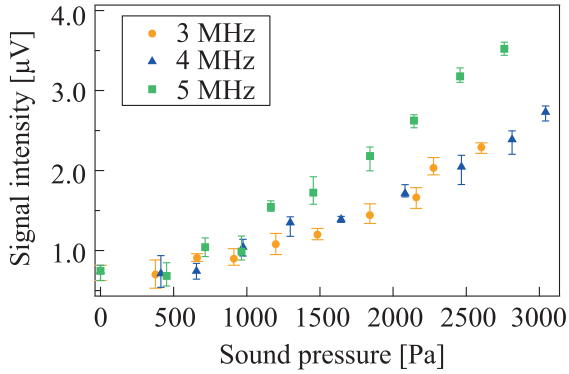

Fig. 3 Signal intensity detected by the SPR stress sensor.

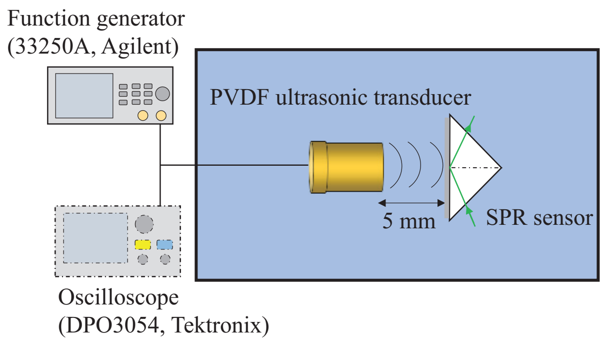

Fig. 4 Measurement system of the reflected waves inside of the prism.

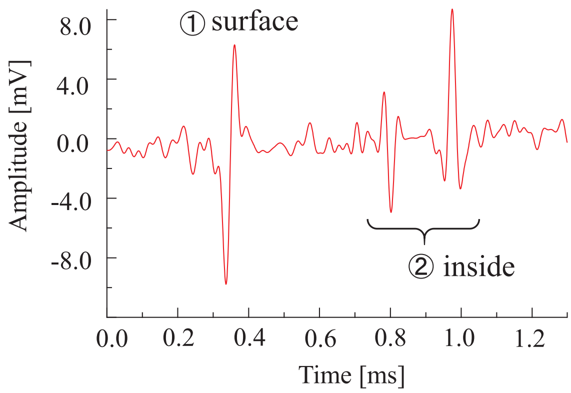

Fig. 5 Detected reflected waves from the sensor.

References

[1] R. Nuster *et al.*,Opt. Express, **15**, 6087 (2007).
[2] M. Xu *et al.*, Rev. Sci. Instrum., **77**, 041101 (2006).
[3] S. Zeng *et al.*, Sens. Actuators, B, Chem., **176**, 1128-1133 (2013).
[4] A. Schilling *et al.*, Appl. Phys. Lett, **69**, 27, 4159-4161 (1996)
[5] H. Sano *et al.*, Jpn. J. Appl. Phys, **58**, SGGA02. (2019)