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Frequency characteristics of surface plasmon resonance ultrasonic receiver

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1. Introduction

Application of surface plasmon resonance (SPR) to ultrasound detection has attracted attention. SPR sensor has a simple structure, non-resonant ultrasonic characteristics and are expected to have a broadband and flat frequency response [1]. We suggested a two-layer SPR sensor and showed high frequency characteristics up to 10 MHz. In this study, we tried to investigate lower frequency characteristics of the SPR ultrasonic sensors.

2. Principle of experiments

Free electrons vibrate in metal thin films. Surface plasmon waves (SPW) are then formed at the metal surface due to these free electrons. In this experiment, a Kretschmann configuration sensor, which is commonly used to excite SPR, was used [2]. A *p*-polarized laser beam was directed to the metal thin film from the prism side at an angle where total internal reflection occurred. SPR can be induced when the wave number of the evanescent wave (EWV) generated on the metal thin film matches the wave number of the SPW. Here,

$$k_{SPW} = k_0\sqrt{\frac{\varepsilon_m n_a^2}{\varepsilon_m + n_a^2}} \quad (1),$$

$$k_{EVW} = k_0 n_p \sin\theta \quad (2),$$

where k_0 is the wavenumber of the electromagnetic wave in vacuum, ε_m is the dielectric constant of the metal, n_a is the refractive index of the adjacent medium, n_p is the refractive index of the prism, and θ is the angle of incidence of the laser on the thin film. When the incident angle of the laser is the angle at which the wavenumbers coincide, i.e., the resonance angle, the intensity of the reflected light is significantly reduced due to the generation of SPR. If the resonance state changes due to ultrasonic pressure, the reflected light intensity at the observation angle also changes. Ultrasonic waveforms can be observed by continuously monitoring the reflected light intensity as it changes at the fixed observation angle.

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3. Experimental Method

3.1 Sensor configuration

A Kretschmann-type SPR sensor was fabricated by depositing Ag (31 nm thick) and Au (5 nm thick) films on a glass prism (SF11, refractive index 1.795) by the electron beam deposition (**Fig. 1**) [3]. By depositing a Au thin film on the top of the Ag thin film, we have successfully extended the lifetime of SPR sensors by a factor of three.

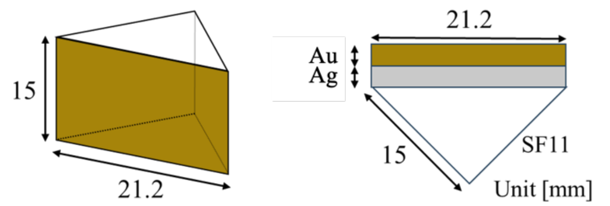


Fig. 1 The fabricated SPR sensor with metal layers

3.2 Experimental conditions

In the experimental setup shown in **Fig. 2**, the laser beam (532 nm) was incident on the SPR sensor at an angle of 56.05°. Additionally, a focused ultrasonic transducer (B0.5K20I PF25, JAPAN PROBE) was used to irradiate the SPR sensor. One-cycle of sinusoidal ultrasound (500 kHz or 300 kHz) was applied to the transducer. The reflected light from the SPR sensor was input to a differential photodiode (PDB435A, THORLABS), and the AC component of the output (V_{AC}) was observed by an oscilloscope (DPO7254C, Tektronix) after passing through an amplifier (NF, SA-420F5). For comparison, a needle-type ultrasonic transducer (UT) (effective diameter 1.00 mm, Onda) was used to observe the focused ultrasound. For the frequency analysis of observed ultrasound, the amplified waves measured by the SPR sensor were compared with the waves observed by UT.

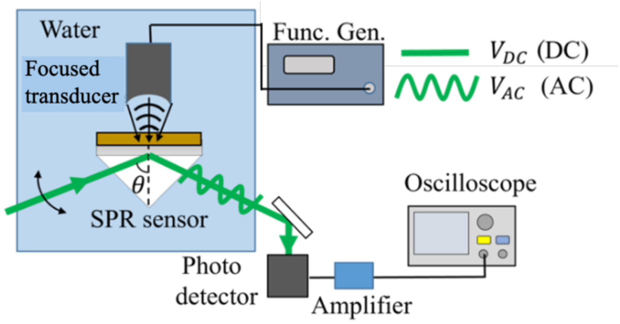


Fig. 2 The experimental system.

4. Results and discussion

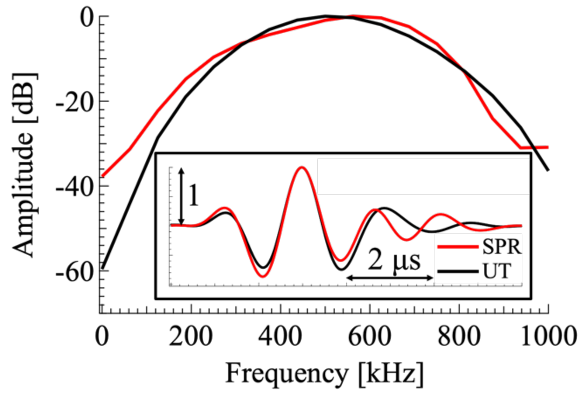
Fig. 3 shows the ultrasonic waveforms observed using the SPR sensor and UT, and their frequency characteristics. In the case of ultrasound radiation at 500 kHz, the frequency range components were from 187.5 kHz to 812 kHz (-20 dB). Similarly, at 300 kHz, it was from 62.5 kHz to 625 kHz. The results by SPR and UT were almost in good agreement.

For comparison of ultrasonic waveforms, both waves observed by SPR and UT were normalized by their maximum amplitudes. A slight phase deviation was observed after the positive second peak in the waveforms. A comparison between the ultrasonic waveforms at 2 MHz and 500 kHz is shown in **Fig. 4**[4]. Following the observed ultrasonic waveform at 2 MHz, a sequence of smaller amplitude waveforms was found. This may be effects of ultrasonic waves in the prism on the laser beam. It means that when measuring lower frequency ultrasonic waves, there is a possibility that ultrasound in the prism may also affect the laser beam propagation.

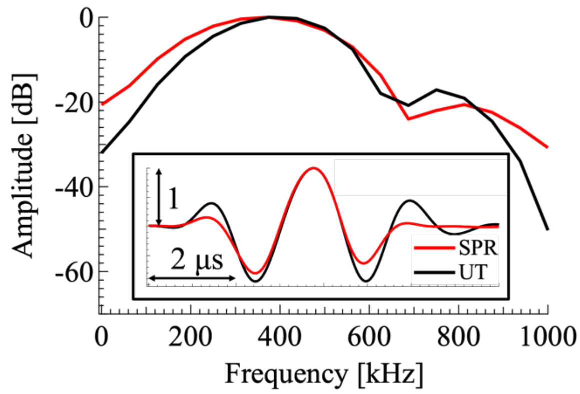
Fig. 5 shows the frequency characteristics of the SPR sensor. Higher frequency data are from our former study [4]. The values on the vertical axis are normalized by the amplitude spectra of the same ultrasonic waves observed using UT. The results show a comparatively flat frequency characteristic from 250 kHz to 6 MHz.

5 Summary

We investigated the lower frequency characteristics of the SPR sensor. The SPR sensor could observe lower frequency components down to 250 kHz. However, as the frequency decreases, the wavelength increases, and the impact of ultrasound within the prism may become significant. Next step is to avoid the incidence of ultrasound to the sensor prism.



(a)



(b)

Fig. 3 Ultrasonic waveform and frequency characteristics (a) 500 kHz and (b) 300 kHz.

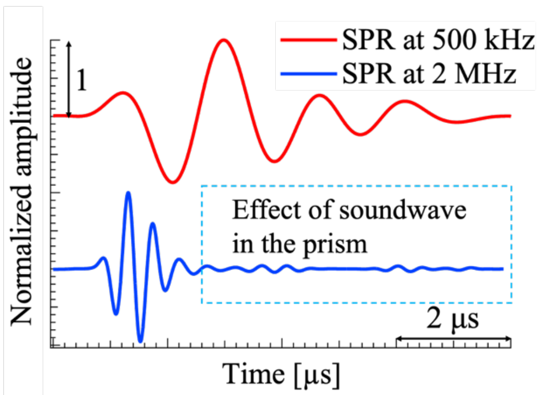


Fig. 4 Ultrasonic waveforms observation by SPR.

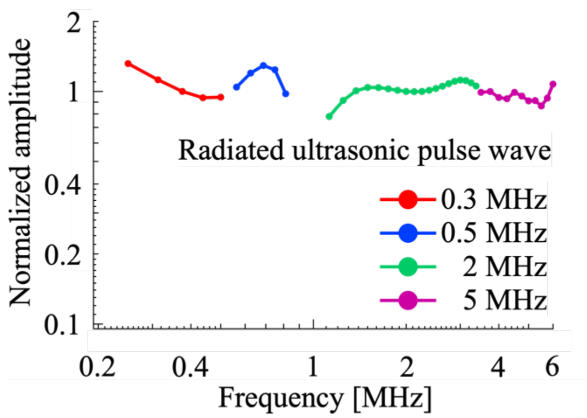


Fig. 5 Broadband frequency response of the SPR sensor (normalized by UT data).

References

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