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An in-plane velocimeter using low frequency acousto-optic modulator with silica nanofoam
シリカナノフォームを用いた低周波数音響光学変調器による面内速度計

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1. Introduction

Silica nanofoam[1] is a porous material with a nanometer structure produced through a sol-gel process, and has been used as a thermal insulator[2]. The nanofoam can work as a good acoustic matching layer for airborne ultrasonic transducer[3][4] for highly sensitive and wideband ultrasound transmission/detection since the nanofoam has an extremely low acoustic impedance. The nanofoam may also have a possibility as an acousto-optic device[5] because of its very low sound speed and optical transparency[6].

In this paper, we have fabricated a 510-kHz acousto-optic modulator using silica nanofoam, and applied it to an in-plane velocimeter with low frequency-shift heterodyne detection.

2. Application of silica nanofoam to AOM and measurement of in-plane speed

Figure 1 shows the experimental setup for measuring in-plane velocity. Silica nanofoam is attached to a 510-kHz ultrasonic transducer. Density and dimensions of silica nanofoam are 200 kg/m^3 and 10x10x5 mm. Input electric power to the transducer is 0.2 W. The wavelength of the ultrasound in the nanofoam is 0.20 mm. A light of He–Ne laser (λ = 632.8 nm) travels through the nanofoam in the direction vertical to the ultrasound propagation. The laser light is diffracted by the ultrasound. In this case, the phenomena subject to the Raman-Nath diffraction theory. The angle of the first order diffracted lights ares calculated to be 0.18 degrees.

The ±1st order diffracted lights are extracted using a beam stop, and focused with a biconvex lens on the measured surface. The diffracted lights have frequency shift of $\pm\Omega$ and illuminates the surface at an angle of θ. The incident angle θ was 2.6 degrees. The back-scattered lights with the Doppler shift due to the surface motion can be written as

$$E_{-1} = A_{-1}\cos[\{\omega - \Omega + 2\pi(\tfrac{2V\cos\theta}{\lambda} - \tfrac{U\sin\theta}{\lambda})\}t + \phi]$$
$$E_{1} = A_{1}\cos[\{\omega + \Omega + 2\pi(\tfrac{2V\cos\theta}{\lambda} + \tfrac{U\sin\theta}{\lambda})\}t].$$

Here, ω is the angular frequency of the laser light, Ω is the angular frequency of the ultrasound, V is out-of-plane velocity and U is in-plane velocity. A current measured by a PD is written by

$$i \propto \overline{|E_{-1} + E_{1}|^2} = A_{-1}^2/2 + A_1^2/2 + A_{-1}A_1[\cos\{(2\Omega + 2\pi\tfrac{2U\sin\theta}{\lambda})t + \phi\}.$$

A beat signal that is twice the ultrasound frequency is detected, and the frequency shift $\frac{2U\sin\theta}{\lambda}$ is proportional to the in-plane velocity. We measured rotating speed of a disk revolved by a DC motor which was perpendicular to the 0th order diffracted light. Back of the surface was white-and-black patterned so that we could measure the rotating speed using an infrared sensor. The pulse from the sensor is counted to find the speed. **Fig. 2** shows the spectrum of the beat signals for the rotating disk. When the disk did not rotate, peak of the spectrum was at 1020 kHz. The peak of the spectrum moved in response to the rotating speed. **Fig. 3** shows the relationship between the frequency shift and the rotating speed and the straight line shows theoretical value of 143kHz/m/s.

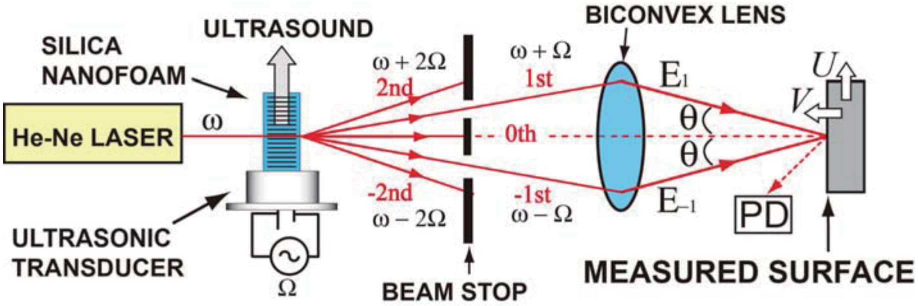

Fig. 1 Experimental set up for measuring in-plane velocity using the nanofoam-based AOM.

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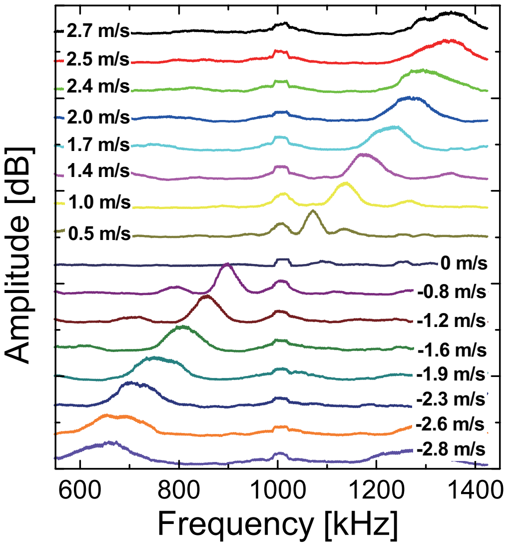

Fig. 2 Spectrum of the beat signals for a rotating disk.

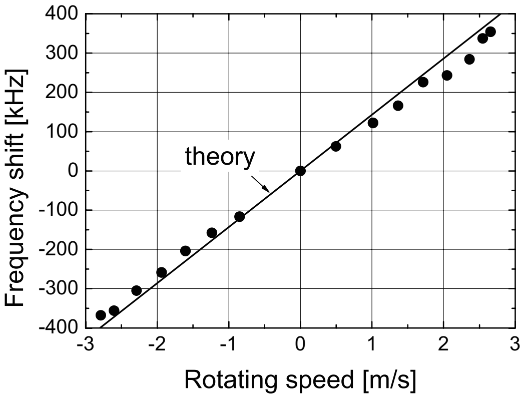

Fig. 3 Frequency shift vs. rotating speed.

Next, we measured the vibration amplitude of a 28.53-kHz conical horn attached to a bolt-clamped Langevin transducer as shown in F**ig. 4**. We focused the ±1st order diffracted lights at the side surface of the conical horn. At the same time, we measured the vibration amplitude using a commercial laser Doppler velocimeter (LDV) at the end of the horn. **Fig. 5** shows the spectrum of the beat signals for the bolt-clamped Langevin transducer. The peaks appeared at the interval of 28.53 kHz on the both sides of 1020 kHz. **Fig. 6** shows the vibration amplitude calculated from fig. 5.

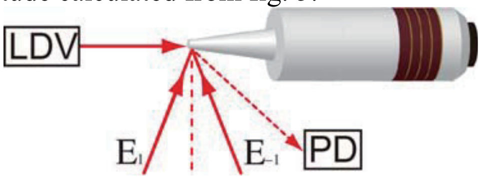

Fig. 4 Measurement set up for the vibration amplitude of bolt-clamped Langevin transducer.

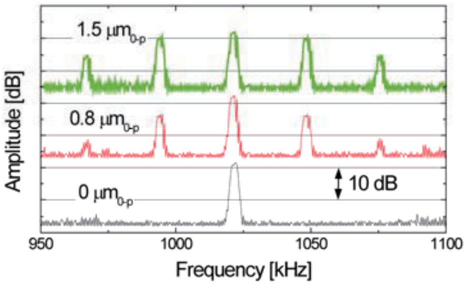

Fig. 5 Spectrum of beat signals for the bolt-clamped Langevin transducer.

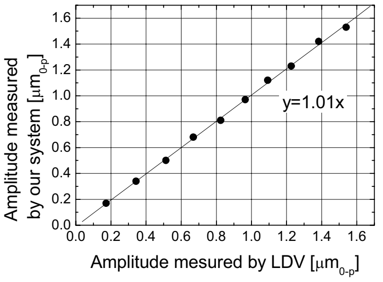

Fig. 6 Vibration amplitude of the bolt-clamped Langevin transducer.

3. Conclusions

We fabricated an in-plane heterodyne Doppler velocimeter using silica-nanofoam-based on AOM. The shift frequency is lower than conventional AOM since the sound speed in nanofoam is extremely low. The acousto-optic efficiency of the nanofoam is high, and the Raman-Nath diffraction can be occurred with a small electrical input.

Acknowledge

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