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Measuring of Vibrational Distribution of Piezoelectric Device by Speckle Interferometry with Pulsed Laser

パルスレーザを用いたスペックル干渉法による圧電デバイスの振動分布測定

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1. Introduction

When designing piezoelectric devices, measuring the vibrational mode is very important. To measure the mode, several techniques, e.g., X-ray diffraction and the laser Doppler effect, are used [1].

We have studied the laser speckle interferometry which enables us to measure in-plane and out-of-plane vibration modes quickly without scanning [2]. To improve the measurement sensitivity of the laser spcekle interferometry, a pulsed laser method was suggested [3]. In this research, we analyzed the suggested method, and evaluated the advantages of this method quantitatively.

2. Experimental

When a rough surface of piezoelectric devices is irradiated with a laser, the mutual interference of scattered light produces an intensity pattern, i.e., a speckle. We assume that the intensity of the speckle I is given by

$$I = I_0 + \gamma\cos(2k(x+a)), \qquad (1)$$

where $k = 2\pi/\lambda$, λ is the wavelength of the laser, I_0 is the average intensity, γ is the visibility of the speckle, a is the vibration amplitude, and x is the vibrational displacement [4]. The two methods that enable us to obtain the vibrational distribution from the equation (1) are introduced in the following section.

2.1 Burst Method

While the vibrating device is irradiated with a laser, we obtain two images of the intensity distribution of the device with the CCD camera: one in the resonance state and the other in the non-resonance state. The vibrating period is much shorter than the interval of the CCD exposure time, and hence the obtained intensity in the resonance state is the mean value over the exposure time of the CCD. The intensity difference between two images, ΔI_1, is given by

$$\Delta I_1 = \gamma\left(1 - \frac{\sin(4ka)}{4ka}\right). \qquad (2)$$

We obtain the vibrational distribution from equation (2).

2.2 Pulsed Laser Method

The piezoelectric device is irradiated with the pulsed laser synchronized with the resonance frequency of the device, which enables us to obtain the intensity distribution in the momentary state in vibrating with the CCD camera. The intensity difference ΔI_2 between the state of the maximum positive displacement, stateA_+, and the other state is given by

$$\Delta I_2 = \gamma\left(1 - \cos\left(2kd(\theta)\right)\right), \qquad (3)$$

where $d(\theta)$ and θ are the displacement and the phase shift from the stateA_+, respectively. $d(\theta)$ is given by $d(\theta)=a(1+\sin(\theta-\pi/2))$. If a is remarkably smaller than the wavelength of the laser λ, ΔI_2 takes the maximum value when $\theta = \pi$. When a = 1 nm, and λ = 655 nm, the ratio of $\Delta I_2/\Delta I_1$ is given by

$$\frac{\Delta I_2}{\Delta I_1} \sim 12, \qquad (4)$$

which means that the pulsed laser method increases the measurement sensitivity by a factor of 12.

Figure 1 shows a block diagram of the measurement system. To drive the piezoelectric device, a function generator (AFG3102C) generated a sine wave signal from channel 1 and a square-wave pulse (duty ratio was 20 %) for laser pulse irradiation from channel 2. These signals were synchronized, and the phase difference between these signals was variable.

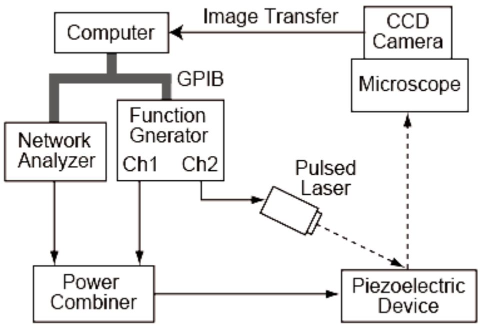

Fig. 1: Block diagram of pulsed laser method.

3. Results and Discussion

As mentioned above, the pulsed laser method visualizes the vibration mode most effectively when $\theta = \pi$. To demonstrate this, we measured the thickness shear mode of the SMD 3225-type AT-cut quartz resonator, which had a nominal frequency of 9.85 MHz. Figure 2 shows the experimental results of the vibrational distribution for several values of θ. The output power to drive resonator was -20 dBm. The white regions on the electrode indicate high-amplitude vibration. The vibrational distribution was most clearly obtained when $\theta = \pi$.

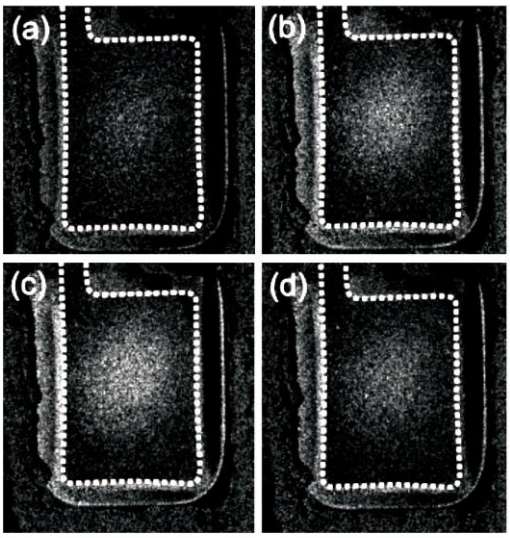

Fig. 2: Vibrational distribution of the SMD 3225-type AT-cut quartz resonator measured by pulsed laser method when θ was (a) $\pi / 2$, (b) $3\pi / 4$, (c) π, and (d) $3\pi / 2$. Output power to drive resonator was -20 dBm. Dashed curves indicate the shape of the electrode.

Figure 3 shows the results for the burst method and the pulsed laser method. The vibrational distribution obtained by the latter method is more clearly visualized.

While the distribution was barely obtained at the output power of -7 dBm in the burst method, it was obtained even at the output power of -28 dBm in the pulsed laser method (not seen in Fig. 3). Therefore, the displacement sensitivity increases by a factor of 11, which is in close agreement with equation (4).

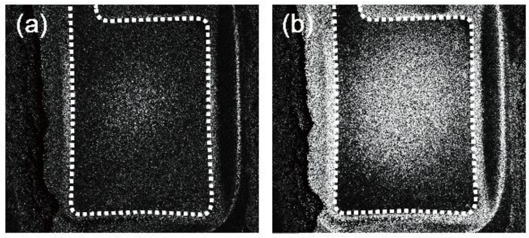

Fig. 3: Results for (a) burst method and (b) plused laser method. Output power to drive resonator was -7 dBm in both cases. Dashed curves indicate the shape of the electrode.

4. Conclusions

We measured the vibrational distribution of the thickness shear mode by the laser speckle interferometry, and compared the results of the burst method and the pulsed laser method. It was found that the pulsed laser method improved the measurement sensitivity by a factor of 11.

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