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Measurement of Surface Acoustic Wave in Soft Material Using Swept-Source Optical Coherence Tomography
波長走査光断層測定による低弾性定数材料の表面波測定

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1. Introduction

Use of endoscope is one of practical ways to find incipience tumors, but to discriminate whether they are benignant or malignant is rather difficult. It is known that, in many cases, malignant tumor is harder than benignant tumor. If we can know elastic properties of tumor at the time of first examination, patients' burden and medical spending would be minimized. Thus, elastography is highlighted in this decade.

Optical coherence elastography (OCE)[1,2], based on optical coherence tomography (OCT), has increasingly become attractive, as it takes advantage of the high spatial resolution of the OCT imaging.[3)] Especially, a possibility of OCE in identifying and localizing small lesions within tissue is arousing interest as an competitive technology to ultrasound and magnetic resonance measuments.[3)] If the propagation velocity of surface acoustic wave (SAW) is measured, the elastic constant can be estimated.[4)] Li *et al.*[5)] detected generated surface waves on skin and phantom using a phase-sensitive optical coherence tomography (PhS-OCT) and they has successfully evaluated the Young's modulus of thick biological phantoms and human skin *in vivo*.

In this study, we try to detect velocity of SAW using swept-source optical coherence tomography (SS-OCT), which is already commercialized and widely available. The depth scanning in SS-OCT is limited by the sweep rate of the SS light source which is as fast as 20–100 kHz. However, the lateral scanning is performed using a mechanical moving mirrors, and is relatively slow. The resultant flame rate for the B-mode imaging is less than 100 fps in most of the commercial OCT system. A method to estimate the SAW velocity using such slow imaging system is discussed in this report.

2. Experimental method

Figure 1(a) shows the experimental system. We excite SAW on agar sample with different concentration: 1, 2 and 3%. One point on the agar sample is vibrated with a small stick (a pick). The pick is connected to the corn of a small loudspeaker. For this study, continuous waves, from 500 Hz to 1000 Hz are excited, and the agar samples are examined using the SS-OCT. **Figures 1(b) and 1(c)** show scanning directions for OCT imaging. Direction 1 and 3 are parallel to the SAW propagation. Direction 2 and 4 are vertical to the SAW propagation. **Figure 2** shows an example of agar's surface tomographic view. From this picture, we measured the wavelength at each frequency. This wavelength observed in the OCT image is

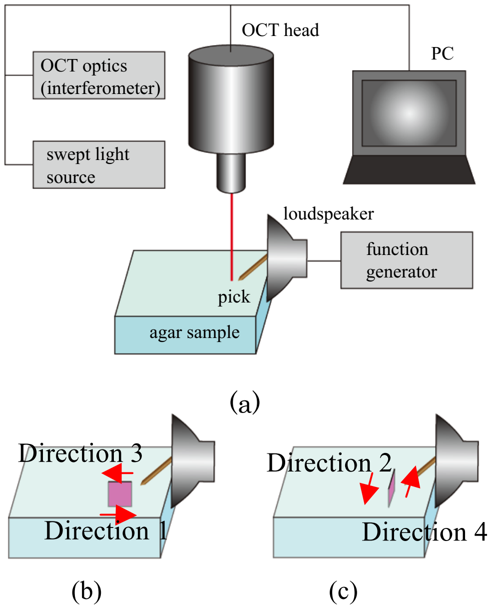

Fig. 1 (a) Set up for surface wave generation and detection. (b) Scanning parallel direction. (c) Scanning vertical direction.

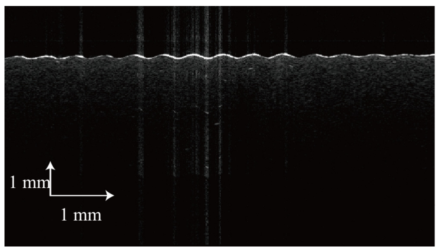

Fig.2 An example of agar OCT image.

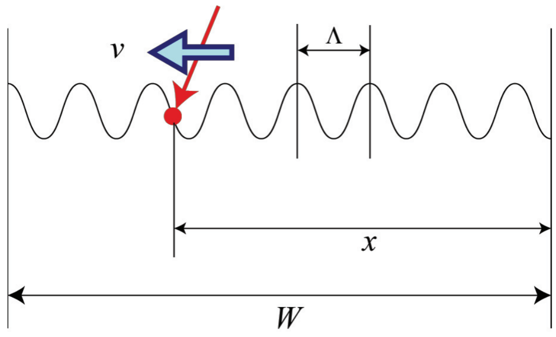

Fig.3 Detection of SAW velocity.

different from the actual SAW wavelength since the imaging is much slower than the propagation of SAW. Using this observed wavelength, we figured out the SAW velocity of each agar based on the theory explained in the next chapter.

3. Estimation of surface acoustic wave velocity

Here, let us explain how to figure out SAW velocity from the OCT images. Surface of agar observed by OCT is illustrated in **Fig. 3**. Lateral scanning velocity v in OCT can be expressed as:

$$v = nW, \tag{3.1}$$

where n is the scanning rate and W is the width of scan. The place of observation can be written as:

$$x = vt, \tag{3.2}$$

where t is the time. Surface acoustic wave displacement is expressed as:

$$y = A\cos(kx - 2\pi f t)$$

$$= A\cos 2\pi f\left(\frac{1}{c} - \frac{1}{v}\right), \tag{3.3}$$

where c is the velocity, f is the frequency and k is the wave number of SAW. If the spatial period observed in the OCT image is Λ,

$$f\left|\frac{1}{c} - \frac{1}{v}\right|\Lambda = 1 \tag{3.4}$$

is satisfied. Thus, from eq. (3.4) we can figure out the SAW velocity. In addition, when OCT scans vertically to the SAW propagation, c is to be ∞, and we can also figure out the OCT scanning velocity.

4. Experimental results

From the results for direction 2 and 4, scanning speed was figured out using eq. (3.4). The average scanning velocity was 0.27 m/s. As an example, **Fig. 4** shows the spatial period for

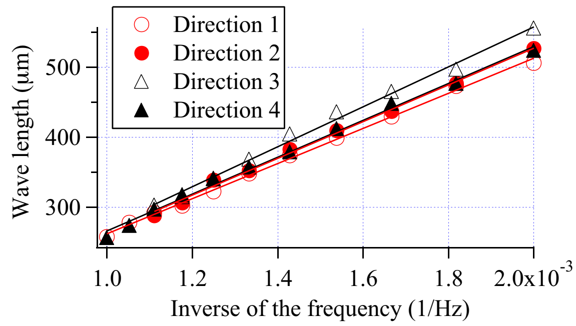

Fig. 4 Wavelengths of each direction for the sample of 2%.

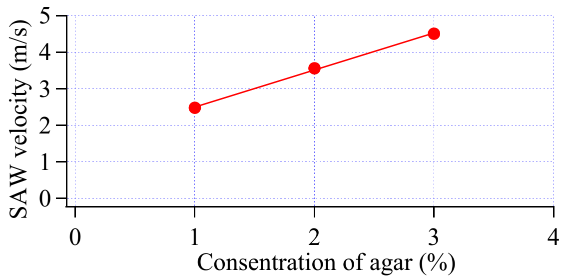

Fig. 5 The SAW velocity for 1, 2 and 3% agar.

each direction measured using the 2% agar sample. From the scanning velocity and the slope for direction 1 of **Fig. 4**, the SAW velocity was figured out using eq. (3.4). **Figure 5** shows the SAW velocity estimated for 1, 2 and 3% agar. The velocities were 2.48, 3.56 and 4.51 m/s for the 1, 2 and 3% agar samples, respectively. The SAW velocity of each agar sample increased linearly with the increase in the agar concentration.

5. Conclusion

We have presented a technique to characterize the mechanical properties of agar samples using SS-OCT. By calculation and analyzing the observed spatial period of SAW, we evaluated the SAW velocity. We have shown that the velocity increased linearly with increase in the agar concentration.

References

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