C-Mode Observation of Nonlinearity Parameter $B/A$ by Automatic Measurement
自動測定による非線形パラメータ $B/A$ の C モード観察

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1. Introduction
A method to automatically measure the nonlinearity parameter $B/A$ of a small volume sample set in the focal region of focused Gaussian beam was previously developed.$[1]$ In this paper, by shifting the focus on a thin sliced biological tissue, the measurement is repeatedly conducted many times. Using this result, the C-mode image to show nonuniform distribution of $B/A$ is generated.

2. System and Automatic Measurement
In Fig.1, the LN transducer with an inverted polarization layer generates and detects the burst wave of fundamental ($f=18.6$ MHz) and second harmonic (2$f=37.2$ MHz). Through a solid acoustic lens with a 5 mm aperture radius, a focused Gaussian beam of 10.65 mm focal length is emanated. The $1/e$ beam width is 0.22 mm at the focus. Intermediating a 1-mm thick ring spacer, a tungsten rod and a 1-mm thick polystyrene-plate acoustic window provide a sample layer. To keep the sample temperature at 20°C, cooling water is circulated around the water couplant, and all the acoustic system of Fig.1 is placed in a fixed temperature chamber.

When the layer is empty, the reflected wave amplitude $P_{1b0}$ from the rear surface of the window is measured. This rod position to set the surface on the focal plane is defined as $z_s=0$. After filling the layer with distilled water, the layer thickness is obtained from the time interval $\tau_W$ of two bursts reflected from the rod and the rear surface of the window as $L=c_W\tau_W/2$. When the rod is set at $z_s=-L$ so that the end is located on the focal plane, the FFT is executed for the reflected wave to obtain the nonlinear second harmonic amplitude $P_{NW}$. Further, when dual frequency bursts of $f$ and 2$f$ are radiated, the amplitudes $P_{W1}$ and $P_{W2}$ and the relative phase delay $\Phi_W$ of the 2$f$ component in the wave reflected from the rod are also measured.

After filling the layer with a sample, at $z_s=0$, we measure the time interval $\tau_S$ of the bursts reflected from the rear surface of the window and the rod as well as the amplitude $P_{1b}$ of the wave reflected from the rear surface. Then the sound speed is determined as $c=2L/\tau_S$, and the density $\rho$ is derived from $P_{1b}/P_{1b0}$.$[2]$ Moving the rod to $z_s=-cL/c_W$, the amplitudes $P_{S1}$ and $P_{S2}$ and phase delay $\Phi_S$ in the wave reflected from the rod are similarly obtained for the dual frequency sound. The attenuation coefficients $a_1$ at $f$ and $a_2$ at 2$f$ are obtained from the insertion loss $P_{W1}/P_{S1}$ and $P_{W2}/P_{S2}$. The magnitude of velocity dispersion $\Delta k=(\Phi_W-\Phi_S)/2L$ is also obtained. Measuring the nonlinear second harmonic $P_{NS}$ in the wave reflected from the rod, $B/A$ is finally determined.$[3]$ These processes are sequentially run with LabVIEW program.

3. Multipoint Measurement for Liquids
The result of the above $B/A$ measurement repeated 256 times on a point of the layer filling water or ethylene glycol is shown in Fig.2. $B/A$ was...

Fig.1. Cross sectional view of acoustic system.

Fig.2. Repeated measurement result for liquids.
measured with the standard deviation smaller than 1%. Each measurement takes 5 s, so that 22 minutes are taken for 256 time measurements.

Scanning the beam on the sample layer by two-dimensionally moving the x-y stage installing the lens and LN transducer with a 0.2 mm step in the extent of 3×3 mm², $B/A$ was measured for water at 16×16=256 points. The result is shown in Fig.3 in gray scale. Due to the setting error of $z_s$, it can result in $\Delta k\neq 0$ even for non-dispersive liquids. To keep $2L|\Delta k|$ less than 0.01 rad, the rod surface must be parallel to the x-y plane with error less than 0.1°. Due to this difficulty, the measured $B/A$ values are scattered as shown in Fig.3(a). Assuming $\Delta k=0$ in water, the scatter becomes small as in Fig.3(b).

4. Application to Biological Samples

Using two microtome blades set parallel with a 1.3 mm spacing, biological samples were sliced and set in the layer with saline or distilled water. The lateral size was set smaller than the inner diameter of the spacer. The measured $B/A$ for an area of 3×3 mm² scanned by the beam is shown in Fig.4. The standard deviation of 10%, which is larger than in liquids, in the results for pig liver(a) and chicken liver(b) suggests non-uniformity of $B/A$. In the sample of squid mantle(c), $B/A$ is observed to gradually change with the location.

5. Conclusion

Thin biological samples were observed with C mode display of automatically measured $B/A$. It was suggested that $B/A$ is not uniform in the small area. The enhancement of the measurement speed and accuracy will be investigated hereafter.

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References