Effect of M-series PRBS Modulation on the Time Resolution in Correlation Photoacoustics

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Synopsis. Time resolution in the first kind correlation photoacoustics using the M-series PRBS mechanical light modulator was experimentally checked. It was found that the time resolution limited by the mechanical chopper was more determinative than that by the microphone detector or the time delay unit in the experimental system used.

It has been demonstrated[1,2] that the introduction of the cross-correlation technique into photoacoustic spectroscopy enables a new kind of experiment such as measuring the delay time of photoacoustic output signal with respect to the exciting light, or recording the absorption spectra of a definite layer lying deep in a layered material. The delay time measurement is conducted by the correlation photoacoustics of the first kind, where the spectra are obtained from the measurement of cross-correlation function $C(\tau)$ between an exciting input and the resultant photoacoustic output as a function of delay time τ. The measurement of the absorption spectra of a layer is referred to as the correlation photoacoustics of the second kind, where the cross-correlation function is recorded as a function of the exciting wavelength λ at the fixed delay time τ_0 of the reference signal.

In the first kind correlation photoacoustics we are interested in the shortest limit of the delay time measurable by the present experimental system. A similar problem occurs in the measurement of the second kind correlation spectra in the sense that one would be interested in the shortest distance between layers which can be resolved from each other by the present system. Both of these problems are reduced to the same term of "time resolution", since the distance between layers can be converted into time scale if the thermal conductivity of the material is known, and *vice versa.*

Experimental

A block diagram for the first and second kind correlation photoacoustics is shown in Fig. 1. In the present work only the first kind correlation spectra have been measured. The exciting light from the He–Ne laser source(NEC, 50 mw) was mechanically modulated by the chopper which gives a pseudo random binary sequence(PRBS) modulaton based on the M-series (maximum-length linear shift register) binary sequence. The modulated light was introduced into a photoacoustic cell to irradiate the carbon black sample. The output was detected by a microphone (SONY, electret condenser type, FET buffer included, No. 8-814-196-50) and was fed into a correlator, essentially an integral circuit. The reference signal detected by a photo-diode was delayed by the variable amount of τ at T. D. U. (Time Delay Unit) and led into the correlator, the output of which was recorded as a function of τ.

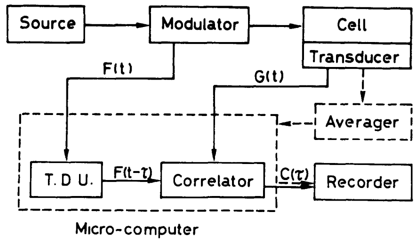

Fig. 1. Block diagram showing the experimental setup for the measurement of the first kind correlation photoacoustic spectra.

Results and Discussion

There are many factors which will influence the limit of experimental time resolution. Some are concerned with the characteristics of the sample measured. One of the major factors coming from the measuring system would be the way of modulating input signal.

Figure 2 shows the power spectrum of the input signal produced by a PRBS chopper with $63(=2^6-1)$ binary bit in a sequence, when rotated at 390 rpm. The upper limit of the modulation frequency contained in the spectrum is around 410 Hz neglecting the higher order components, so that the time resolution attainable by this chopping system would be about 2.5 ms($=1/400$ s) at highest. To improve time resolution, or to increase the highest component of modulating frequecy contained, one has to either raise the rotating speed of the chopper or use other choppers which have larger number of binary bits of the M-series. Figure 3 shows the first kind correlation spectra by the use of the $31(=2^5-1)$ bit and $127(=2^7-1)$ bit PRBS choppers at the rotating speed of 396 rpm. The delay time of about 0.5 ms obtained from the peak position of curve A is considerably smaller than that

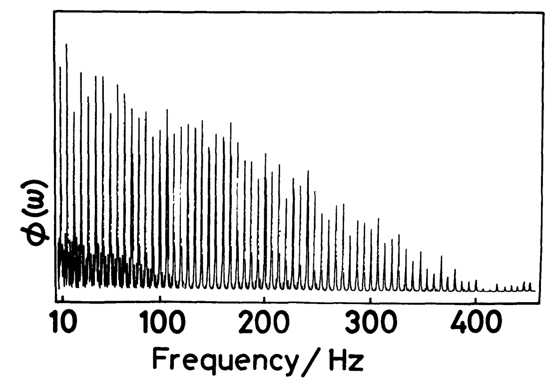

Fig. 2. Power spectrum of the M–series 63 bit PRBS chopper rotated at 396 rpm. Higher frequency part of the spectrum starting from about 410Hz is omitted in the figure.

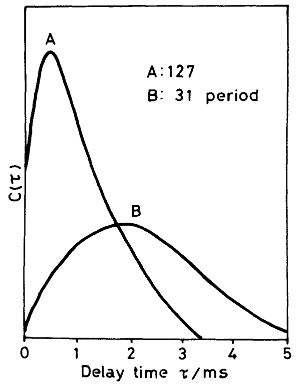

Fig. 3. The first kind correlation photoacoustic spectra of carbon black sample with the use of the 127 bit (A) and 31 bit (B) choppers rotated at 396 rpm.

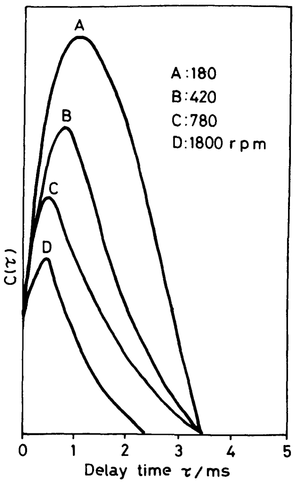

Fig. 4. The first kind correlation photoacoustic spectra of the carbon black sample recorded at the different rotating speeds of the 127 bit PRBS chopper; A: 180, B: 420, C: 780, and D: 1800rpm.

from curve B(about 2 ms), showing that the 127 bit chopper gives much closer value to the delay time of carbon black. Similar experiments using the 255 bit PRBS chopper showed the same line shape and peak position as curve A, indicating that the delay time 0.5ms obtained by the 127 bit chopper gives the lowest τ value when the choppers are rotated at 396 rpm.

Figure 4 shows the change of the first kind correlation spectra of the carbon black at different rotating speeds of the 127 bit PRBS chopper. The peak position of curve D agrees with that of curve C within the experimental error. Similar results have been obtained with the use of a 255 bit chopper at lower rotating speeds (approximately at half speeds). A 511 ($=2^9-1$) bit chopper which comes next to the 255 bit one would be the biggest possible one in view of manufacturing and/or stability of rotation at high speeds. We are not yet successful in driving the 511 bit chopper at a sufficient stability probably due to the lack of driving power. The time resolution practically obtainable with the use of the 127 bit chopper would be $(1/127\times1/30)\,\mathrm{s}\fallingdotseq260\ \mu\mathrm{s}$ at highest when rotated at 1800 rpm.

The ways of signal detection and signal processing are other important factors which determine the limit of time resolution. The microphone used in the present experiment has the working range up to about 15 kHz. Consequently the time resolution with the use of this microphone could reach to 70 μs which is sufficiently shorter than 260 μs, the time resolution limited by the 127 bit chopper.

The slowest part of the signal processing of the present system lies in the time delay unit(T. D. U., Fig.1) which digitally delays the reference signal by certain amount of τ by a microcomputer(NEC, TK-80) program. The limit of time resolution of this unit is determined by the speed of the microprocessor(D8080-AFC) of TK-80 as tens of microseconds[3], which is a comparable order of magnitude to that limited by the microphone. The correlator in our system is made by the analog unit which works much faster than the TK-80 digital unit, so that no limit of time resolution from the correlator unit will be put in the present system of signal processing.

Great improvements in time resolution would be expected by the use of a laser source in place of the xenon lamp source, an acousto-optic modulating system in place of the mechanical PRBS chopping system, or a piezoelectric detecting system in place of the microphonic detection. Effect of these replacements will be studied on conditions developed.

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References

1) K. Kato, S. Ishino and Y. Sugitani: *Chem. Lett.* **1980**, 783.
2) Y. Sugitani: *Kagaku no Ryoiki* **35**, 8 (1981); Y. Sugitani, A. Uejima and K. Kato: *J. Photoacoustics* **1**, 217 (1982).
3) TK-80E/80 USER'S MANUAL, IEM-560D (NEC), (1978).