이중변조를 적용한 테라헬츠파 신호대 잡음비의 향상

Improvement of the signal-to-noise ratios of THz waves using a double modulation

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The interest of THz technology has been growing fast due to the potential of its vast applications. Today's THz technology pursues semiconductor based miniature electronic devices operating at undeveloped electromagnetic frequency band between 100 GHz and 10 THz. Tremendous research progresses on THz technology have been made for decades. However, it is limited in the power and performance of THz sources and systems for real applications. Recently, there are encouraging breakthrough in THz sources. THz technology has been extended its applications to imaging, warfare agent detection, medical diagnosis, material characterization. For these applications, THz-TDS (THz time-domain spectroscopy has been widely utilized [1]. In the characterizations of aqueous materials, absorptions of THz waves are enormous so that the difficulties of the weak THz wave detections are occurred. In this paper, to improve signal-to-noise ratios (SNR) in the THz wave detection, the double modulation technique has been applied.

The double modulation is a technique similar to encoding information on a carrier wave in telecommunications. The signal, already modulated at a lower frequency f_2 is additionally modulated at an higher frequency f_1 by an optical chopper.

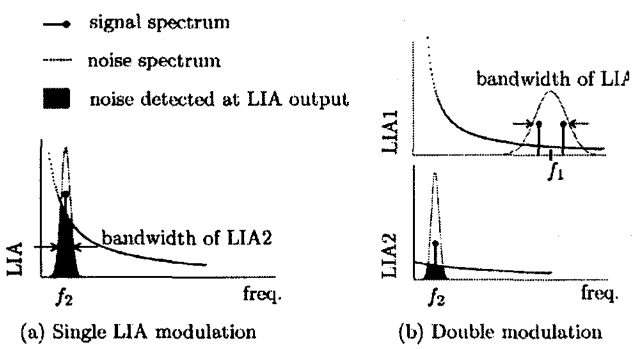

Fig. 1. Diagrammatic comparison of single and double modulation; (a) single LIA modualtion. The signal is modulated at a frequency f2 by a galvanometric shaker. (b) double modulation. The input of the second LIA, the signal is modulated at f2. :

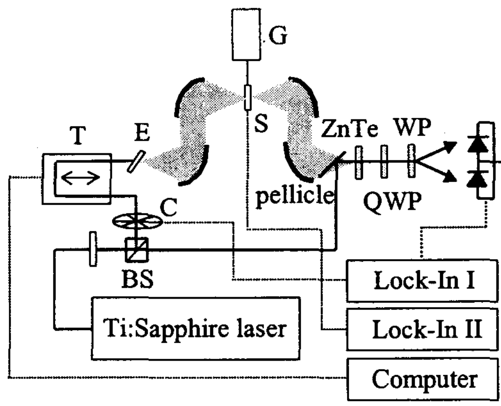

Fig. 2. Schematic setup of the experiment; BS: beam splitter, C: chopper, E: emitter, G: gavanometer, S: sample, T; translation stage, WP: Wollaston polarizer, QWP: quarter wave plate.

The frequency f_1 equivalent to the carrier frequency, is then removed in the detection system through demodulation [2]. Frequency modulation is diagrammatically described in Fig. 1. The advantage of double modulation is that the noise level at the higher modulation frequency is less than that at the lower frequency. The main source of noise in the THz-TDS experiment is the mode-locked Ti/sapphire laser, with an 1/f noise characteristic.

The lock-in amplification (LIA) passes the signal through a very narrow band filter to reject any variations not at the modulation frequency. A schematic layout of double modulation as implemented in our experiment is shown in Fig. 2. The pump beam is first modulated at 2 kHz by the mechanical chopper and then modulated at 66 Hz by the gavanometer shaker. The double modulated T-ray signal is converted to a polarization modulation of the probe beam using electro-optic detection [3]. Balanced photodiodes detect the polarization modulation of the probe beam, and the first LIA, acting as a mixer, demodulates the chopper f_1. The second LIA detects the modulated by the galvanometer at f2 and provides a complex output representing the THz waveform at a given pump-probe delay.

Figure 3 shows the noise properties of THz waves in single and double modulations. In the double modulation, the SNR was 118,000 while the counterpart in the single modulation was 25,600. The noise level in the double modulation was 4 times less than that in the single modulation. However, the maximum values of THz waves at peaks were almost same so that the SNR in the double modulation was 4 times greater than that in the single modulation.

In conclusion, the double modulation was applied to improve the SNR of THz wave. The SNR in the double modulation was 4 times improved, compared to that in the single modulation. This method can be applied to the THz-TDS to characterize aqueous materials or thin films which absorb THz wave enormously or show very small phase changes by thin films.

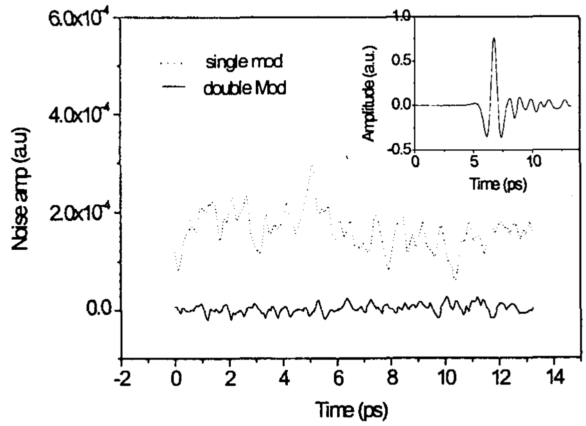

Fig. 3. The noise propeties of THz waves; solid: double modulation, dotted: single modulation, the inlet diagram indicates THz waveform.

[1] G. Gruner (Ed.), Millimeter and submillimeter wave spectroscopy of solids, Topics in Applied Physics, vol. 74, Springer, Berlin, Germany (1998).

[2] S. V. Frolov, Z. V. Vardeny, Review of Scientific Instruments 69(3), 1257 (1998).

[3] Q. Wu, X.-C. Zhang, Applied Physics Letters 67(24), 3523 (1995).