Rotary Optical Delay Line for High Speed Scanning of Terahertz Pulse

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***Abstract*—Rotary optical delay line (RODL) uses a rotating reflective surface that gives a linear delay length with respect to the rotation angle. High speed scanning of terahertz pulse up to 400 Hz was realized by using the RODL. Operation characteristics of the RODL in high speed scanning will be presented.**

I. Introduction And Background

FOR rapid terahertz (THz) imaging and real time monitoring of THz pulses, a high speed and high repetition rate optical delay line is essential. For rapid terahertz imaging and the real-time monitoring of terahertz pulses, a high-speed and high-repetition-rate scanning optical delay line (ODL) is required in order to sample terahertz pulses quickly. Beside high scanning rate, good linearity in delay length, large scan amplitude, and robustness are desirable parameters of the optical delay line. A galvanometer-based oscillating optical delay line (OODL) is usually used for high speed scanning of THz pulses.[1)] In this delay line, two retroreflecting mirrors oscillate a fixed distance with a given frequency. But the position and velocity of the mirrors change sinusoidally, so the delay length of optical beam is not linear. In order to get a linear high speed scan rate ODL, a rotary type optical delay line (RODL) is proposed. [2-3)] In this study, we report on high speed scanning of THz pulse by using the RODL.

II. Experimental

The operation principle of RODL is described in Ref [3]. A rotary reflector with six reflecting blade was used (Fig. 1). The radius r and rotation angle $\Delta\theta$ of the rotating reflector are 2 cm and $\pi/3$, respectively. Maximum delay length obtained by the RODL is $\Delta l = 2r\Delta\theta = 4.2cm$ (140 ps). The material of the reflector is stainless steel (SUS 304) and the reflective surfaces were polished for higher reflection of the incident laser beam. The reflector was mounted on an AC servo motor (Yaskawa SGMPH-01, Max. speed 5000 rpm, Rated speed 3000 rpm).

For a high speed terahertz pulse measurement, a low noise current preamplifier (Stanford Research Systems, SR 570), and a data acquisition (DAQ) system (National Instruments NI PXI-6132, 3MS/s, 14 bits) were utilized. The terahertz pulses obtained by the RODL and a linear stage optical delay line were compared to verify the linearity of the RODL. In order to apply the RODL for the detection of terahertz pulses, a typical pump and probe setup for terahertz pulse generation was used, as shown in Fig. 2.

Fig. 1 Rotary optical delay line with six reflecting blades

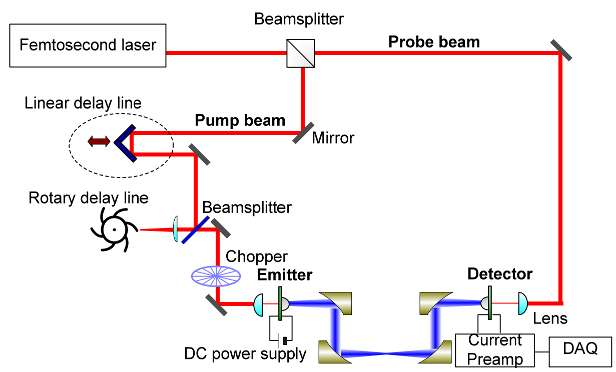

Fig. 2 Experimental setup for generation and detection of pulsed terahertz wave with a linear stage optical delay line and a RODL

III. Results

Scanning speed of the RODL is changed from 1 Hz to 400 Hz by controlling the rotating speed of the AC servomotor. Fig.3 shows the comparison of THz spectrum obtained using a linear step motor delay line (MDL) and the RODL. The positions of absorption lines of water vapor in air are identical in two delay lines, which confirm the linearity of the RODL regardless of the scanning speed. Note that no rock-in amplifier or chopper wheel was used in the measurement with RODL. The terahertz signal is directly obtained by the DAQ system via a current preamplifier. The results confirm the linearity as well as the possibility for high speed spectroscopic applications of the RODL.

The scan speed of the RODL goes up in proportional to rotation speed of the servo motor. Fig. 4 shows the amplitude of the terahertz wave pulse trains as a function of time when the scan repetition rate changes from 50 Hz to 400 Hz. We can see

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that the time interval between terahertz pulses agrees exactly with their repetition frequencies. Since the optical scan range of each reflecting blade is 2.1 cm, the scan repetition rate of 400 Hz corresponds to a longitudinal scan speed of 8.4 m/s at the servo motor rotation speed of 4,000 rpm.

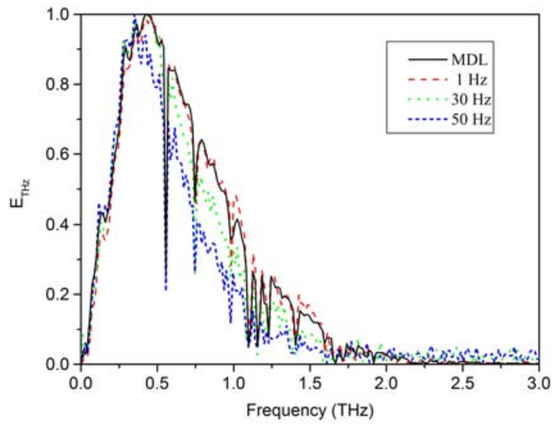

Fig. 3 Comparison of THz spectrum obtained using a linear step motor delay line (MDL) and the RODL

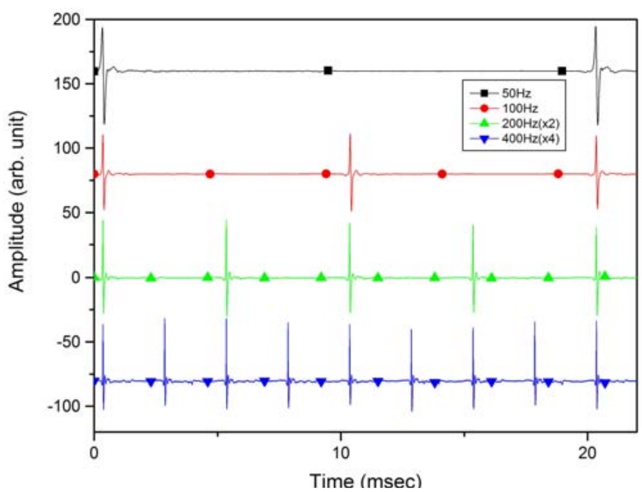

Fig. 4 Trains of the terahertz wave pulse measured by the RODL as a function of time when the scan repetition rate is changed from 50 Hz to 400 Hz.

The signal-to-noise ratio (SNR) of the terahertz pulse was measured as a function of scan speed by changing the rotating speed of RODL blade. At a high repetition rate greater than 50 Hz, the SNR decrease from 500 to less than 100. But the low SNR at high repetition rate can be improved by adding up multiple waveforms and taking the average. As shown in Fig. 5, several thousands of the SNR can be obtained at slow scan operation.

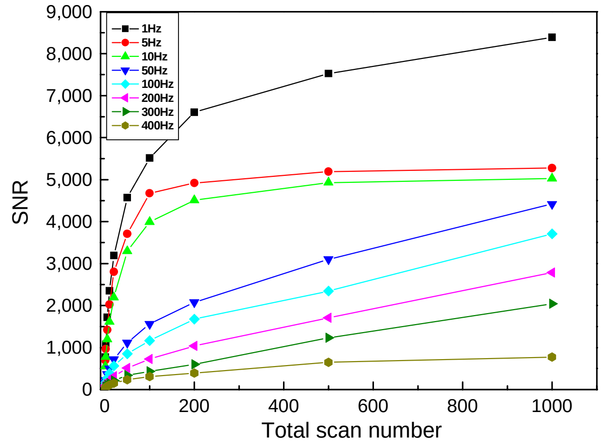

Fig. 7 Signal-to-noise ratio (SNR) for THz pulses as a function of scan repetition rate of the fast RODL

IV. CONCLUSION

We demonstrated a rotary type rapid-scanning optical delay line that can perform delay length scans up to 2.1 cm at a scan repetition rate of 400 Hz while maintaining excellent linearity. The rotary optical delay line (RODL) was successfully applied to generation and detection of terahertz pulses with high speed for the first time. High signal-to-noise ratio up to a few thousand can be obtained by averaging multiple terahertz pulses at high scan speed.

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