Terahertz Wave Emission from Liquid Metal

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***Abstract*—We observe the broadband terahertz wave emission from liquid gallium line excited by sub-picosecond laser pulses. THz waveforms from both liquid water line and liquid gallium line with the same pulse energy and pulse duration are compared. Additionally, THz signals generated from liquid gallium line with six different diameters are reported here. The results show that, the THz field strength from liquid gallium line is 1.5 times stronger than that from water. We also observe slight decrease of THz peak field with the increase of the diameter of the gallium line.**

I. INTRODUCTION

SOLID state metals were initial targets to generate terahertz (THz) wave from optical rectification with femtosecond laser excitation [1]-[2]. Recently, coherent THz wave emission from metal foils excited by intense laser pulses has been studied [3]-[4]. Liao et al. reported the coherent THz wave emission with a pulse energy as high as 55 mJ from the rear surface of a copper foil using an intense picosecond laser pulse, wherein the coherent transition radiation dominates the electron acceleration process [4]. However, the solid metal targets can be completely destroyed after a single laser shot, and such single-shot emission limits its further application. To resolve this problem, we attempt to use a flowing liquid metal line for THz wave emission. In this work, THz signals from liquid metal and water are compared.

Compared to other liquid metals, liquid Gallium (LG) is a promising candidate for THz source due to the following properties. Firstly, the melting point of gallium is 29.8 °C, which can be easily operated in the experiments. The density of LG is 5 times higher than several other candidates such as Cesium, Rubidium, and Phosphorus, which also have relative low melting points. Additionally, LG is non-toxic and safer compared with Mercury, the most commonly known liquid metal. According to these properties, LG has had various applications in X-ray generation in the last decade [5]-[6].

In this paper, the experimental results of THz wave generation from a flowing LG line under single-color optical excitation is reported. The THz signal is studied and compared with the water under the same experimental condition. Besides, the THz waves measured with six needle diameters are investigated.

II. RESULTS

Fig. 1 is the photo of a flowing LG line. The inner diameter of the needle is 210 µm. Using a peristaltic pump, we set the flow rate of the LG line to be about 3.7 m/s, which is high enough to bring fresh target area for each laser shot. To maintain the gallium in liquid state, a heater is used to control the temperature of liquid samples at 35 ºC. Laser pulses (0.4 mJ) are focused at the LG line to generate THz radiation. The pulse duration is 372 fs and the beam diameter at focus is about 5 µm. More details about the experimental setup is reported in our previous work [7]-[8].

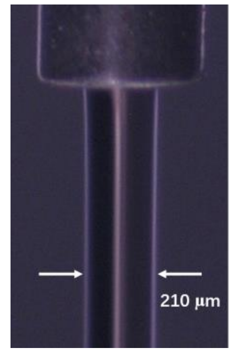

Fig. 1. Photo of a flowing LG line. The inside diameter of the needle is 210 µm. LG has a surface tension of 0.708 N/m at 29.8 °C, which is 10 times higher than that of water (0.0712 N/m). The high surface tension helps to form a better surface of a flowing line.

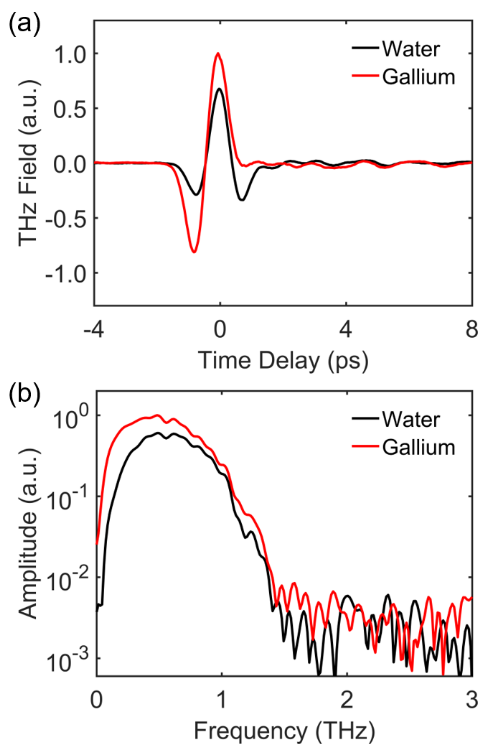

Fig. 2. (a) THz waveforms generated from water and LG line, respectively. **(b)** Corresponding comparison in the frequency domain.

The forward propagating THz waveforms from both water and LG are measured and shown in **Fig. 2(a)**. THz field from ionized LG is 1.5 times stronger in field than that from water line. This might be attributed to the higher electron density of LG. The corresponding comparison in the frequency domain is shown in Fig. 2(b). The plasma fluorescence from ionized LG line is much brighter than that from water line. Also, second harmonic generation is observed from LG and is measured by a spectrometer.

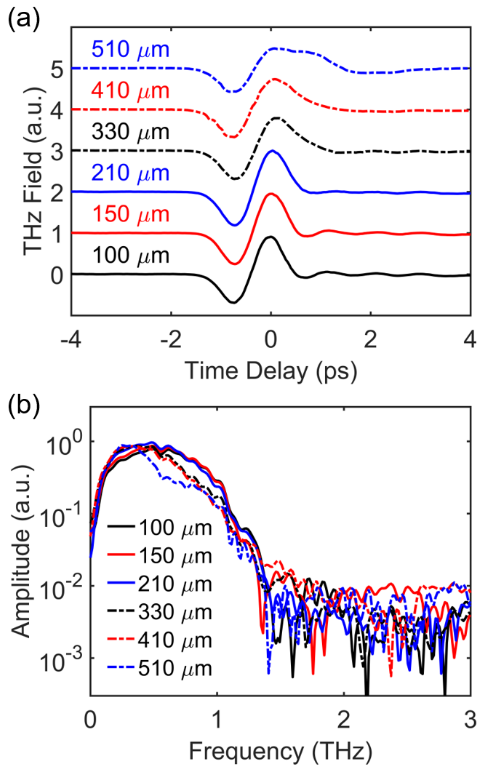

Fig. 3. (a) THz waveforms generated from LG lines with six different needle diameters, which are 100, 150, 210, 330, 410, 510 μm. **(b)** Corresponding frequency spectra of the waveforms.

Furthermore, the THz signals and their corresponding spectra of LG from six needles of different diameters are measured and plotted in **Fig. 3**. The THz signal is sensitive to the position where plasma is generated on LG line. Thus, all measurements are optimized by moving the LG line to maximize the THz peak field. The inner diameters of the six needles are 100, 150, 210, 330, 410, and 510 μm, respectively. The spectra show no remarkable change for the needle diameters of 100, 150 and 210 μm. A slight decrease of THz field appears when larger needle diameters are applied. During the experiments, we observe that the maximal THz radiation is obtained when laser beam is focused on the edge of the LG line, indicating THz wave is generated from the LG surface. Also, the distortion of the THz signal with 510 μm needle diameter might result from the instability of the LG line. In the Fig. 3(b), the spectral ranges for six diameters are close.

III. Summary

In this paper, broadband THz wave generation from LG line excited by sub-picosecond laser pulses is observed. The THz waveforms generated from both water and LG with identical laser pulse duration are investigated and the THz signal from LG is 1.5 times stronger in field than the signal from water. The small variation of THz radiation measured with different needle size indicates that THz wave should be emitted from the surface of LG line. Although the mechanism of THz wave generation from LG is not fully understood yet, this work paves the way for research on intense liquid metal THz sources.

Acknowledgments

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