Increased terahertz emission from SI-GaAs deposited with sub-wavelength spacing metal line array

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***Abstract*—Increased terahertz (THz) emission of surface modified semi-insulating gallium arsenide (SI-GaAs) is reported. A metal line array with sub-wavelength spacing was fabricated via e-beam deposition and THz measurements were done in the transmission excitation geometry. Results show an order of magnitude THz broadband emission enhancement. Pump-power dependent measurements were also utilized which shows a non-linear dependence with the THz integrated intensity. This broadband enhancement is currently attributed to super transmission owing to a non-linear optical effect that may be related to surface plasmon resonance.**

I. INTRODUCTION

SEMICONDUCTORS can emit terahertz radiation when excited via femtosecond (*fs*) laser pulses [1]. This process can proceed by several techniques such as optical rectification [2], surface field THz emitters [3], or photoconductive diodes [4]. The use of photoconductive antennas (PCA's) in terahertz – time domain spectroscopy (THz-TDS) has been widely utilized due to its intense THz emission. One of the most commercially viable substrates for PCA device fabrication is semi-insulating gallium arsenide (SI-GaAs) owing to its high carrier mobility and high breakdown field [5].

Studies to improve THz emitters have been undertaken for the past years. On a related note, the enhancement of electric fields (E-fields) based on sub-wavelength structures may be a viable option in improving THz emitters [6]; which is also related to extraordinary optical transmission [7] which was first reported by *Ebbesen et al* [8]. In this work, we demonstrate the integration of sub-wavelength metal line array (MLA) on SI-GaAs to enhance its THz emission properties.

II. EXPERIMENTAL DETAILS

Standard UV photolithography techniques and e-beam deposition were utilized in the device fabrication. The deposited metal was 150 nm-thick Ni/Au (25 nm/125 nm), thick enough to exceed the skin depth values in the THz region. The width of the metal lines is 50 µm, having a spacing of 300 µm. The spacing served as the sub-wavelength apertures.

Terahertz emission measurements using standard THz-time domain spectroscopy (THz-TDS) were done in the transmission excitation geometry. A 100 *fs* Ti:S laser (λ = 800 nm) served as the excitation. The laser beam was cylindrically-focused onto the back side of the sample near the brewster angle of SI-GaAs at 800 nm (~70^0) [9] (shown in Fig. 1), with a spot FWHM of 3.2 mm, covering 9 SI-GaAs MLA periods. The entire emission cone was efficiently collected onto the PCA detector by using *f*-matched parabolic mirrors. Pump power-dependence of the THz emission was also performed to further investigate the THz enhancement of the MLA structure.

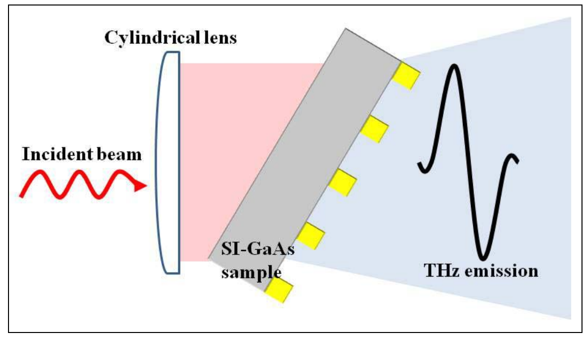

Fig. 1. Schematic diagram showing the sample configuration in the THz-TDS measurements. The excitation beam was cylindrically-focused onto the back side of the sample covering 9 SI-GaAs MLA periods.

III. RESULTS

Figure 2 shows the TDS plots of the THz emission of the bare and MLA SI-GaAs samples at 130 mW excitation laser power. Also shown in the inset are the corresponding FFT spectra. It can be noticed that the amplitude spectrum of the MLA exhibited a higher THz emission by one order of magnitude over a 0.7 THz bandwidth. No significant frequency shifting was observed. As the THz waves exited the surface having the MLA, THz photons interact with the metal's surface electrons resulting in highly localized, intense E-fields at the apertures [6 and 10]. This E-field localization constitutes possible surface plasmon polariton (SPP) resonance.

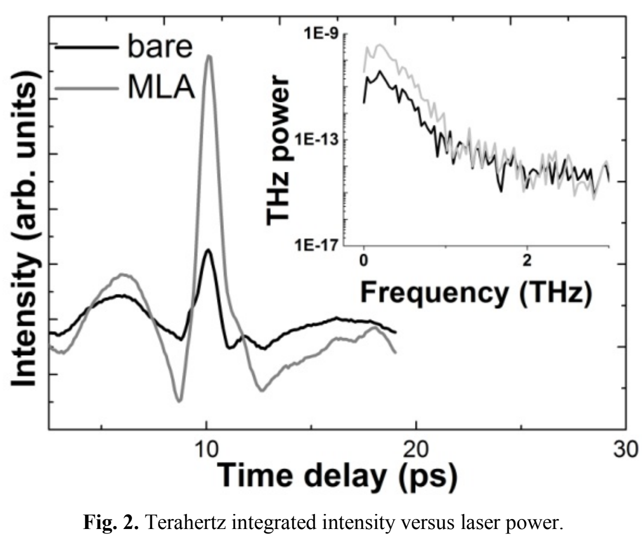

Fig. 2. Terahertz integrated intensity versus laser power.

As an additional study, excitation pump power dependence of the THz emission was performed. However, due to equipment constraints, it was not possible to span the pump power dependence over two orders of magnitude. Nonetheless, the log plot of the results is shown in Fig. 3. The slope, m ≈ 1, of the bare substrate plot is characterized by a linear dependence of the THz integrated intensity on the pump power. However, the MLA exhibits a non-linear dependence, with m = 1.7. These results are consistent with our initial conjecture of a non-linear SPP resonance effect.

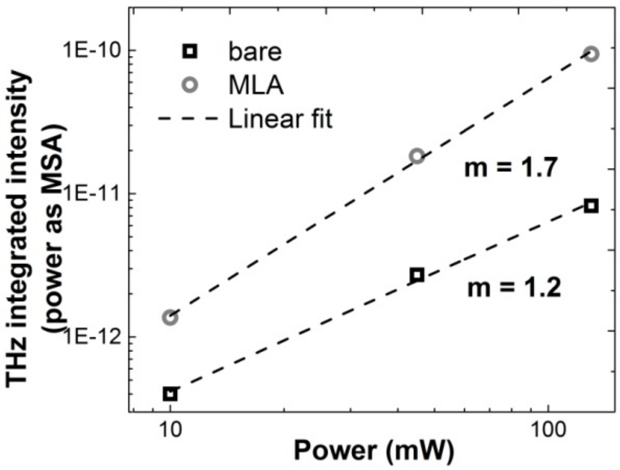

Fig. 3. Terahertz integrated intensity versus laser power.

IV. Summary

A broadband order-of-magnitude enhancement was reported, which we are currently investigating at the moment. The mechanism is temporarily ascribed to super transmission owing to a possible non-linear optical effect that may be directly or indirectly caused by a surface plasmon resonance effect. The incident excitation beam was cylindrically focused onto the sample, and is a broadband source so the resonance condition may have been achieved for a span of frequencies. These experiments could lead into future novel photoconductive antenna designs.

Acknowledgments

This work was done under the auspices of the Office of the Vice President for Academic Affairs of the University of the Philippines - Balik-PhD grant (OVPAA-BPhD-2012-03), the Accelerated Science and Technology Human Resource Development Program of the Department of Science and Technology, and the National Research Council of the Philippines for funding this research. The authors would also like to thank the FIR Center of the University of Fukui for the equipment loan.

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