Terahertz emission from nanophononic structures: the nexus between scale and frequency

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Abstract

We report a newly-found terahertz (THz) generation mechanism, originated from acoustic (AC)standing waves confined within GaN-based piezoelectric layers with discrete elastic parameters, and its frequency controllability by adapting the relevant active layer thicknesses.
Keywords : Tunability Acoutic waves

1. Introduction

Technological advancements in the THz region have already realized various emission and detection sources, some of which has been utilized for spectroscopic imaging systems [1] and utilized for wireless communications [2]. The major technical obstacles for most THz applications still remain such as the absorption loss by water vapour, the difficulty in miniaturizing the system size, and rather poor imaging resolution.

For example, in generic THz imaging systems based on passive photonic components the spatial image resolution is diffraction-limited to a scale similar to the wavelength. In addition, the conventional photonic emission source would rather have broad spectrum which could be advantageous for spectroscopic applications, but the additional filters should be integrated for the general purpose.

In piezoelectric heterostructures, coherent acoustic phonons are significantly enhanced by abrupt potential screening by photo-carriers [3]. The relationship between piezoelectricity and the acoustic phonon waves have been widely studied; e.g., the zone-folded, propagating modes, or THz wave emission from propagating AC waves at the interfaces. Here in this work, we have investigated THz emission characteristics in terms of confined acoustic phonon dynamics from reversely biased *p-i-n* diode structures with strong piezoelectric fields.

2. Experimental Scheme

The representative sample structure used in this work was GaN/InGaN multiple quantum wells (QWs) with AlGaN electron blocking layer with thickness of L between *p*-GaN and QWs , whose band diagram is sketched in Fig. 1a. We note that at very high reverse bias the depletion region can reach through EBL up to *p*-GaN side where the electrons are accumulated with UV laser excitation (denoted by shaded regions). As shown in Fig. 1b, the frequency-double Ti:sapphire laser was used as “pump” for the carrier excitation where another Ti:sapphire laser beam was used for signalling a photoconductive antenna to detect the THz waves.

3. Results

As summarized in Fig. 1b. the prominent THz frequency component agreed well with those of fundamental AC standing wave modes in AlGaN layers (with thickness L) evaluated to be $f=v_s/2L$, where v_s is the sound velocity. The signal amplitude linearly increased with the external reverse bias (not shown here), implying that the accumulated carriers in *p*-GaN/AlGaN interface play an important role for the THz radiations as the depletion region extends beyond the AlGaN layer. The THz radiation from confined AC wave modes has not been reported in the preveous studies with samples without the AlGaN layer [3], whereas significant AC impedance mismatch

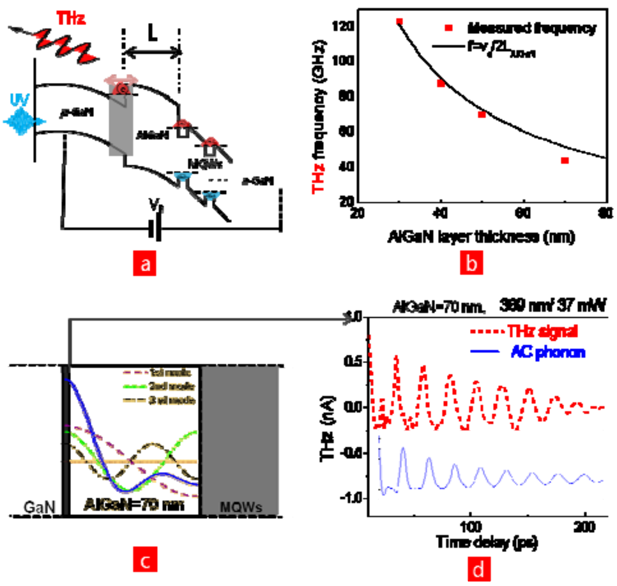

FIGURE 1.(a) Energy band diagram of the sample used in this work. (b) Relation between THz frequency and AlGaN layer thickness. (c) Acoustic standing modes in AlGaN layer. (d) A temporal comparison between a measured THz signal and a simulated acoustic phonon oscillation.

with surrounding layers were recently known to induce the standing wave modes in the case of Au film on a prism and in free-standing Si-membranes.

Without considering the dynamic influence from photocarriers accumulated at the interfaces under high reverse bias, the AC impedance mismatch between GaN and AlGaN was estimated to be about 3 % in our compositions of samples. As manifested in the THz signal amplitude increment with reverse bias, the carrier accumulation at GaN/AlGaN interface is essential for both the AC confinement and THz radiations. Fig. 1c shows the simulation results on the superposition of three multiple harmonic modes of AC standing waves right after the laser excitation. Each component would decays as it evolves in time, where higher modes tend to decay faster. In Fig. 1d, the different time evolution of the standing wave components at the GaN/AlGaN interface was integrated in the simulation result (solid line) which agreed very well with the experimentally measured THz radiation patterns in time domain (dotted line).

4. Conclusion

THz emission measurements have been performed in GaN-based biased heterostructures as a function of the piezoelectric layer thickness in nanoscale. We have confirmed that the THz waves could be closely associated with the confined AC standing waves, which possibly leads us to a new and efficient way to produce spectrally controlled monochromatic THz radiation.

References

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Acknowledgments

This work was supported by the Bioimaging Research Center and "Fusion-Tech. Developments for THz Info. and Comm." program of GIST in 2010.