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Generation of Frequency Tunable Nano-Acoustic Waves by Optical Coherent Control

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Abstract: We have demonstrated an optical coherent control technique to generate nano-acoustic waves in InGaN single-quantum-well with tunable acoustic frequency. The acoustic phonon lifetime of the generated nano-acoustic wave was also measured.

OCIS codes: 320.7100 Ultrafast measurements; 320.7130 Ultrafast processes in condensed matter, including semiconductors

1. Introduction

In previous studies, we have demonstrated the generation and detection of coherent acoustic phonon oscillation in InGaN/GaN multiple quantum wells (MQWs) [1] and the generated acoustic frequency is strictly determined by the MQW periods. For further studies on acoustic phonon properties at different acoustic frequencies, here we report that we have successfully developed an optical coherent control technique for variable acoustic frequency generation. With only an InGaN/GaN single-quantum-well (SQW) sample, we successfully generate frequency tunable nano-acoustic waves (NAWs) up to 1THz. This tunable-frequency NAW source within one fixed sample, resembling a nano-acoustic waveform synthesizer, could thus be utilized for further spectroscopic, nonlinear acoustic, and tunable frequency applications.

For the NAW applications on imaging or electronic control, the property of the NAW propagation has to be known. Recently, it is proved that the dynamic Febry-Perot effect [2], which is able to indicate the existence of acoustic phonons, can be clearly measured by the optical reflectivity pump-probe technique. In following discussions, we also take this method to determine the lifetime of the generated nano-acoustic waves.

2. Experimental setup and results

The optical coherent control setup is a modification of a typical femtosecond transient transmission pump-probe system. A femtosecond Ti:sapphire laser, frequency-doubled by a BBO crystal, provides optical pulses with a ~240fs pulsewidth at a central wavelength of 400nm. One of the samples we used is an $In_{0.2}Ga_{0.8}N$/GaN single-quantum-well (SQW) with a well width of 7nm (sample A), and the other (sample B) is an $In_{019}Ga_{0.81}N$/GaN SQW with a well width of 2.9nm, which determines the nano-acoustic pulsewidth.

In our experiments, we utilized fixed time interval between three pumps to generate a three-pump optical pulse train. Therefore, a tunable-frequency acoustic pulse train can be easily obtained by adjusting the time delays between the optical pumps which were used to generate acoustic waves. By controlling the intervals between pump pulses, we are thus able to control the period of the generated 3-period acoustic pulse. As illustrated in Fig. 1, the NAW generated from the well propagates in opposite directions. One will propagate into the cap layer and be reflected from the surface; the other will propagate into the GaN-buffer layer which is much thicker than the cap layer and then go straight into the sapphire. The acoustic echo from the surface will then be detected in the well region.

The upper limit of the generated NAW frequency is restricted by the well thickness. With sample A, see Fig. 2 (a), the generated acoustic frequency is limited to be 0.5THz due to the 7nm-thick well, corresponding to ~ 1 ps acoustic traveling time, and Fig. 2 (b) shows that we can generate higher acoustic frequency up to 1THz with sample B. Therefore, by choosing a proper well thickness, we can easily obtain NAWs with various frequencies we need in only one SQW sample.

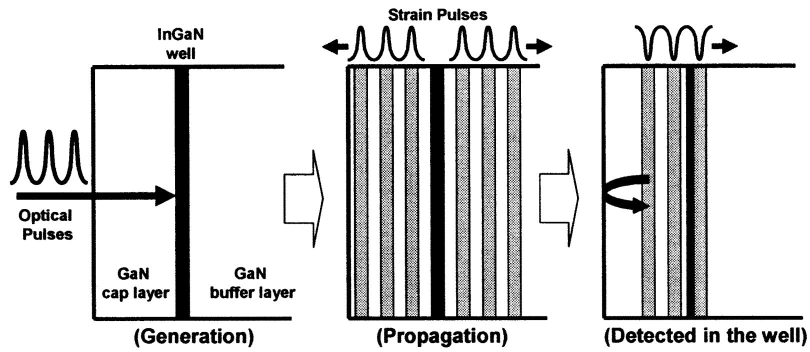

Fig. 1. A schematic diagram illustrating the nano-acoustic wave generation. The echo of the generated acoustic pulse propagating into the cap layer will be detected by the single quantum well.

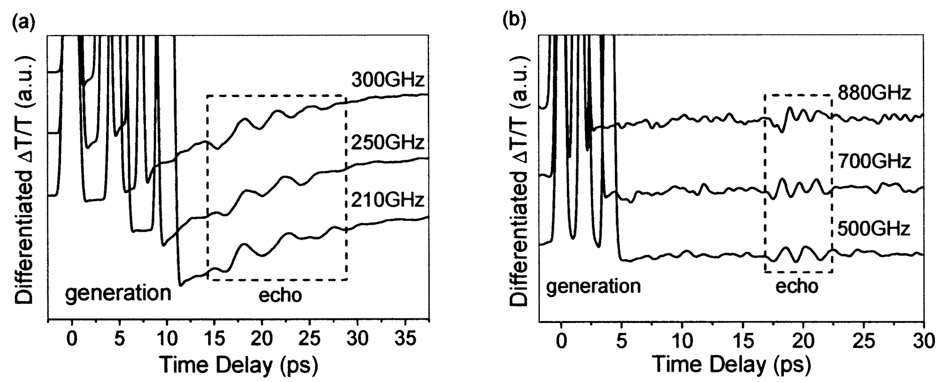

Fig. 2. Differentiated transmission measurement demonstrates the optical coherent control of the generated acoustic frequency in the (a) 7nm-thick and (b) 2.9nm-thick InGaN single-quantum-well.

3. Discussions

When utilizing the optical coherent control to generate NAWs, the saturation problem should be concerned. As shown in Fig. 3 (a), three equal power optical pumps are used to excite the acoustic pulses, and it is obvious that the second and third generated acoustic oscillations are weaker than the first one. It is because that after the excitation of the first optical pulse, the photoexcited carriers in the well region will screen the strength of the piezoelectric field, thus reducing its acoustic generation efficiency. It is thus important to engineer the intensity of the pulse sequence in order to accurately control the generated acoustic waveform. In Fig. 3 (b), we raised the power of the second and third optical pumps to overcome the saturation phenomenon, and a square NAW is successfully generated.

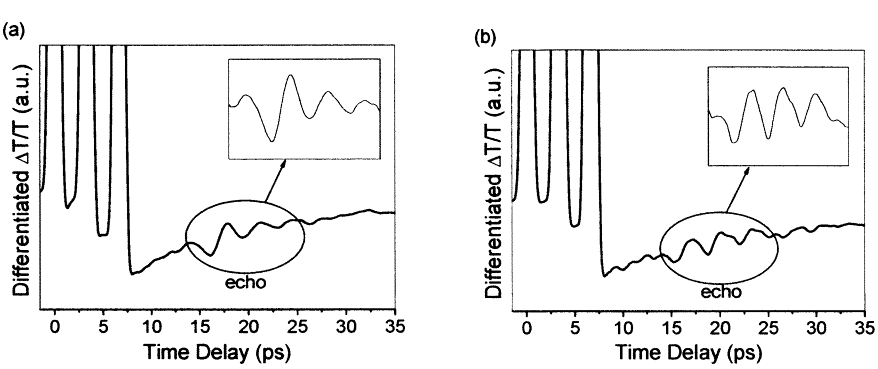

Fig. 3 (a) NAW generated by three optical pumps with the same power. (b) Generated NAW after raising the power of the second and third pumps.

4. Measurement of longitudinal acoustic phonon lifetime

The lifetime of the generated NAW was measured with a combination of a transient reflectivity pump-probe system. Fig. 4 shows the measured transient reflectivity trace with the coherent-control-generated 0.5THz nano-acoustic waves. The measured near 100GHz oscillation is due to the acoustic-wave-induced dynamic Febry-Perot effect. It is obvious that the signal becomes very noisy at around 410 picoseconds because of the acoustic wave propagating into sapphire. An acoustic phonon lifetime longer than 370 ps can thus be obtained, without considering the optical attenuation effect [3]. Frequency dependent acoustic phonon lifetime in GaN will be discussed in the conference.

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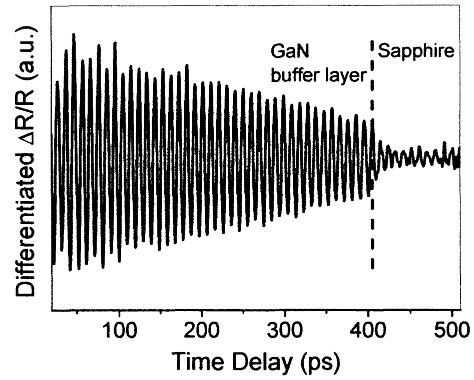

Fig. 4. (a) Differentiated reflection changes as a function of time delay in a GaN sample embedded with a 7nm single quantum well. 0.5THz acoustic wave was generated with coherent control and the traveling of 0.5THz acoustic wave inside the GaN sample was measured. This measurement result indicates a > 370ps phonon lifetime (for longitudinal acoustic phonon in GaN).

References

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