Nano-Acoustic Waveform Synthesis and Second Harmonic Generation of Coherent Acoustic Phonon Oscillations Using Optical Coherent Control

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Abstract: Second harmonic coherent acoustic phonon oscillations were generated in strained InGaN/GaN multiple quantum wells using an optical coherent control technique. This demonstration leads to the nano acoustic waveform synthesis based on optical coherent controls.

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1. Introduction

Large amplitude coherent longitudinal acoustical (LA) phonons in InGaN/GaN MQW's can be initiated and controlled by using femtosecond laser pulses [1,2]. Here we demonstrated that specific acoustic wavelength can be selected by coherent cancellation of unwanted acoustic phonon oscillations. Nano-acoustic waveform synthesis can thus be realized based on this control technique.

2. Experiments and discussions

We performed our experiments using standard femtosecond transmission pump-probe technique based on a Kerr-lens lode-locked Ti:sapphire laser [1,2]. The experiments were conducted at room temperature on 14-period $In_{0.1}GaN/GaN$ MQWs [1]. Contrary to its optical phonon counterpart, the characteristic frequency of a coherent acoustic phonon is mostly determined by the length scale of the underlying heterostructures. In our case, the spatial spectra of coherent LA phonons are related to the distribution of photogenerated carrires [3]. For example, Figure 1(a) shows the measured differential transmission change after femtosecond pulse excitation. The well width and barrier width of the MQW are 2.2 and 7 nm respectively. A clear transmission oscillation due to the induced coherent acoustic phonons can be observed. The observed oscillation period is 1.27 picosecond. Due to the highly asymmetric well width and barrier width, higher harmonic oscillations is expected due to the non-sinusoidal photocarrier distribution according to loaded string model [3]. Figure 1(b) shows the corresponding Fourier power. One sharp peak at 0.8 THz can be seen in the figure, which corresponds to the fundamental oscillation frequency of inverse 1.27 ps in the temporal trace [Fig. 1(a)]. There are also smaller harmonic peaks at 1.6 THz and 2.4 THz corresponding to the second and third harmonic oscillations in Fig. 1(a).

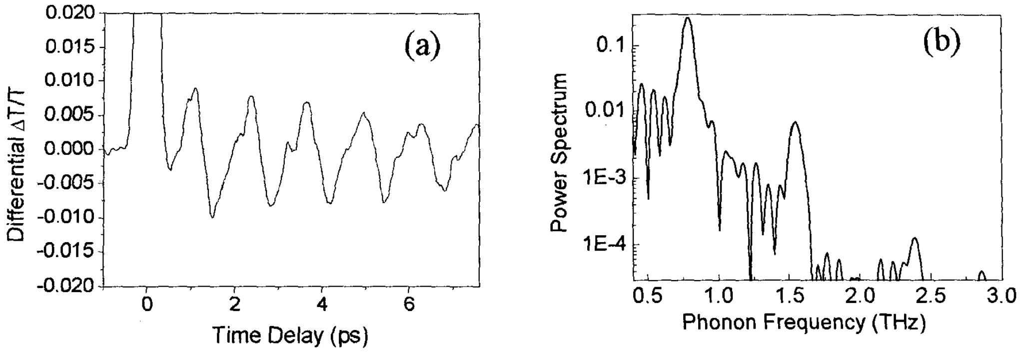

Fig. 1 (a) Measured differential transmission change versus probe delay for a 22Å/70Å InGaN/GaN MQW. The modulated transmission change with a period of 1.27 ps reflects the photoinduced coherent acoustic phonon oscillation. The laser wavelength was 390 nm. (b) Fourier power spectrum of the temporal trace shown in (a). Acoustic frequency components of 0.8, 1.6, and 2.4 THz can be observed with corresponding acoustic wavelengths of 9.2, 4.6, and 3.1 nanometers.

In order to selectively enhance the second harmonic oscillation, we apply coherent optical control to perform the coherent cancellation of the fundamental and third harmonic components with simultaneous amplification of the second harmonic component. This was done by applying another femtosecond UV pulse (called control pulse) into the pump region at 3.18 ps time delay, which is equal to 2.5 fundamental oscillation cycles, 5.0 second harmonic oscillation cycles. This control pulse thus generated another coherent acoustic phonon oscillation of which fundamental oscillations destructively interfered with the original ones while the second harmonic interferes constructively. For example, we show in Figure 2 the measured differential transmission change and its Fourier power spectrum. A clear second harmonic oscillation with a oscillation period of 0.63 picosecond, half of the fundamental oscillation period, can be observed after applying the control pulse at 3.18 ps. Consistent with the time-domain trace, the magnitude of the second harmonic Fourier component was significantly enhanced relative to the fundamental one [Fig 2(b)]. It is also interesting to notice the suppression of the weak third harmonic oscillation, since we are also performing destructive interference for the third harmonic oscillation.

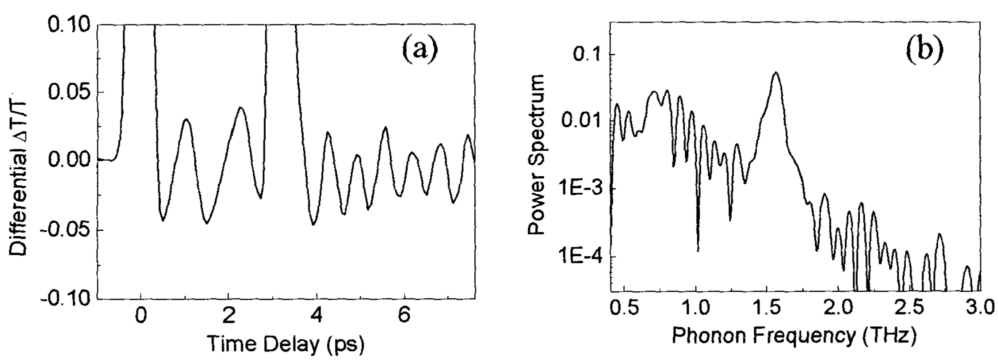

Fig. 2. (a) Measured differentiated transmission changes versus probe delay with a control pulse at 2.5 fundamental oscillation cycles after the first pump pulse. Second harmonic oscillation with a period of 0.63 ps can be clearly observed after applying coherent control with a control pulse. (b) Fourier power spectra of the temporal traces shown in (a) after the incidence of the control pulse. The enhancement of the second harmonic component is evident.

Our demonstration indicates the possibility for nano acoustic waveform synthesis up to a level of nanometer by using optical control technique. This result would lead to many potential applications including material characterizations, coherent control of ionic motions, and even nano nonlinear acoustics.

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