

Lasing characteristics of curved semiconductor nanowires

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Abstract The characteristics of curved semiconductor nanowire (NW) lasers were investigated. The red-shift in the laser spectra with increasing bending angles can be observed much more clearly than that in the photoluminescence (PL) spectra. Due to oscillation of light in resonant cavity, the bending loss of laser exhibits multiple times amplification of that of PL. Furthermore, an abnormal phenomenon of dominant peak switching is found in curved NWs when increasing the pump power, which has been first discovered and reported.

Keywords semiconductor nanowire, lasing characteristics, red-shift, bending loss, dominant peaks

1 Introduction

Semiconductor nanowires (NWs) have attracted a lot of attention for offering highly promising solutions to the realization of nanoscale lasers, due to their unique multifunctional behaviors as gain media, resonance cavities and passive waveguides [1,2]. As one of the most potential building blocks in flexible electronics and photonics [3,4], NWs with curved structures have aroused tremendous interests both from scientific and industrial communities. A huge number of experimental and theoretical studies have been devoted to understanding the waveguiding and luminescence properties of bent NWs [5,6]. However, few reports so far have focused on the lasing characteristics of curved semiconductor NWs. In our very recent work, we reported bending loss and polarization modulation of semiconductor NW lasers [7]. Here in this work, we investigate more lasing characteristics of curved NWs and find that lasing spectra can provide a more efficient method to measure the band structure

modulation under strain. Moreover, an abnormal phenomenon of dominant peak switching in curved NWs when increasing the pump power is first discovered and reported.

2 Experimental methods

CdSe NWs were synthesized by thermal evaporation methods through a vapor-liquid-solid (VLS) process [8]. An alumina boat containing CdSe powder (100 mg) is placed at the center of a horizontal quartz tube as the evaporation source. Si wafers (20-mm-long and 5-mm wide) deposited with 2-nm-thick Au layer were placed downstream in the tube as the substrates. The quartz tube is evacuated and subsequently refilled with high purity N₂ gas four times. After that, the furnace tube is heated to 830°C, and nitrogen gas at a constant rate of 210 sccm (mL·min⁻¹) flows into the tube to maintain a pressure of 480 mbar¹ inside the tube throughout the evaporation period. The growing process lasts for about 1 h. Then the quartz tube is cooled down to room temperature. The below inset in Fig. 1 shows a typical scanning electron microscope (SEM) image of a CdSe NW. We transferred CdSe NWs to a substrate and bent them into different radius through a nanotaper, which can be seen in Fig. 2. As illustrated in Fig. 1 and the upper inset, one end of the NW was excited by 532 nm laser pulses (2 kHz repetition rate, 6 ns pulse width), and the light emission from the other end of CdSe NW was collected for imaging and spectral measurement respectively through a dichroic beam splitter.

3 Results and discussion

According to recent works, red-shift of the localized cathodoluminescence has been observed in the output emission spectra of a curved NW. This phenomenon originates from the deformation-induced reduction in

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1) 1 mbar = 100 Pa

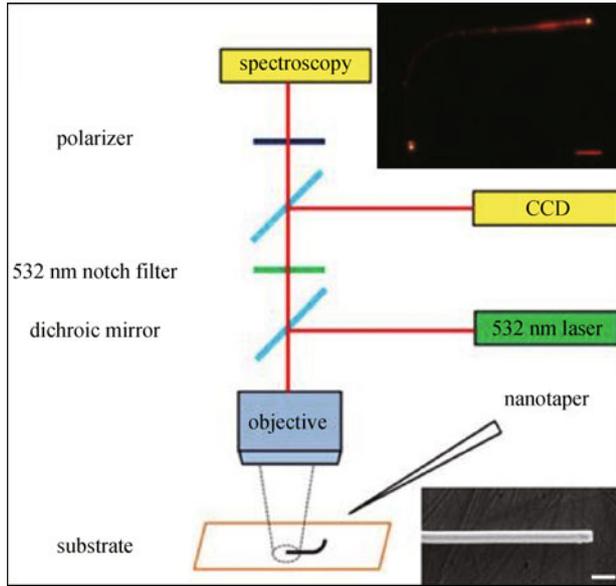


Fig. 1 Schematic diagram of experimental setup for optical excitation and bending process. Upper inset, a dark-field optical image of a bent CdSe nanolaser. The scale bar is 5 μm . Below inset, a typical SEM image of a CdSe NW and the scale bar is 500 nm



Fig. 2 Bright-field optical images of a 35 μm length 450 nm diameter CdSe NW with gradually decreased bending radius

bandgap [6]. However, in our experiment, we could hardly see the red-shift in the photoluminescence (PL) spectra as shown in Fig. 3(a). The peaks of PL spectra obtained from the whole NW are too broad to exhibit the obvious red-shift phenomenon. On the contrary, the red-shift of the peaks in laser spectra are clearly seen since the peaks are significantly narrowed down, as illustrated in Fig. 3(b), indicating that lasing spectra can offer a more efficient method to measure the band structure modulation under strain.

As we know, the spectra detection sensitivity are enhanced dramatically when the absorbing sample is placed inside the laser cavity [9], which can also be applied to the measurement of bending loss. In Fig. 3(c), the bending loss of PL and laser both show exponential

relationships with the bending radius, and the bending loss for laser is multiple times as large as that of PL due to the excitation mechanism of laser that photons travel back and forth between the resonator mirrors. It is noted that such multiple enhancement of bending loss predicts a more sensitive method to measure the perturbation of light induced by fairly small deformation or strain.

Furthermore, we investigate the detailed lasing properties on straight and curved NWs under different pump intensities. Usually, for straight NWs, when we increase the pump power, the dominant peak in lasing spectra will switch from S mode (shorter wavelength, higher energy mode) to L mode (longer wavelength, lower energy mode) due to bandgap renormalization, as illustrated in Figs. 4(a) and 4(b). Similar results are reported in previous work [10,11]. While in curved NWs, a very interesting

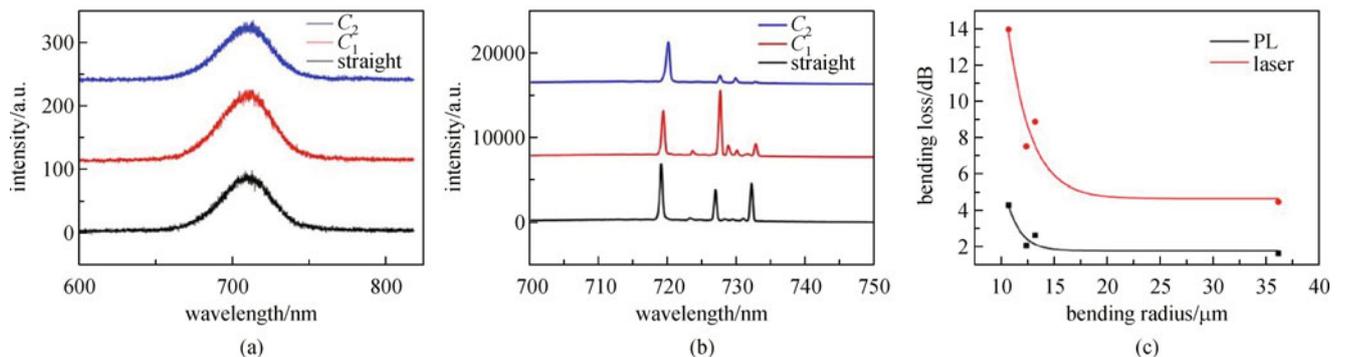


Fig. 3 (a) Output PL emissions spectra of straight and bent NW at the same pumping power, where C_1 and C_2 represent the curvature radius and $C_1 > C_2$; (b) output laser emissions spectra of straight and bent NW; (c) plot of bending loss versus bending radius of PL and laser. Black exponential fitting line is for PL, and red one for laser

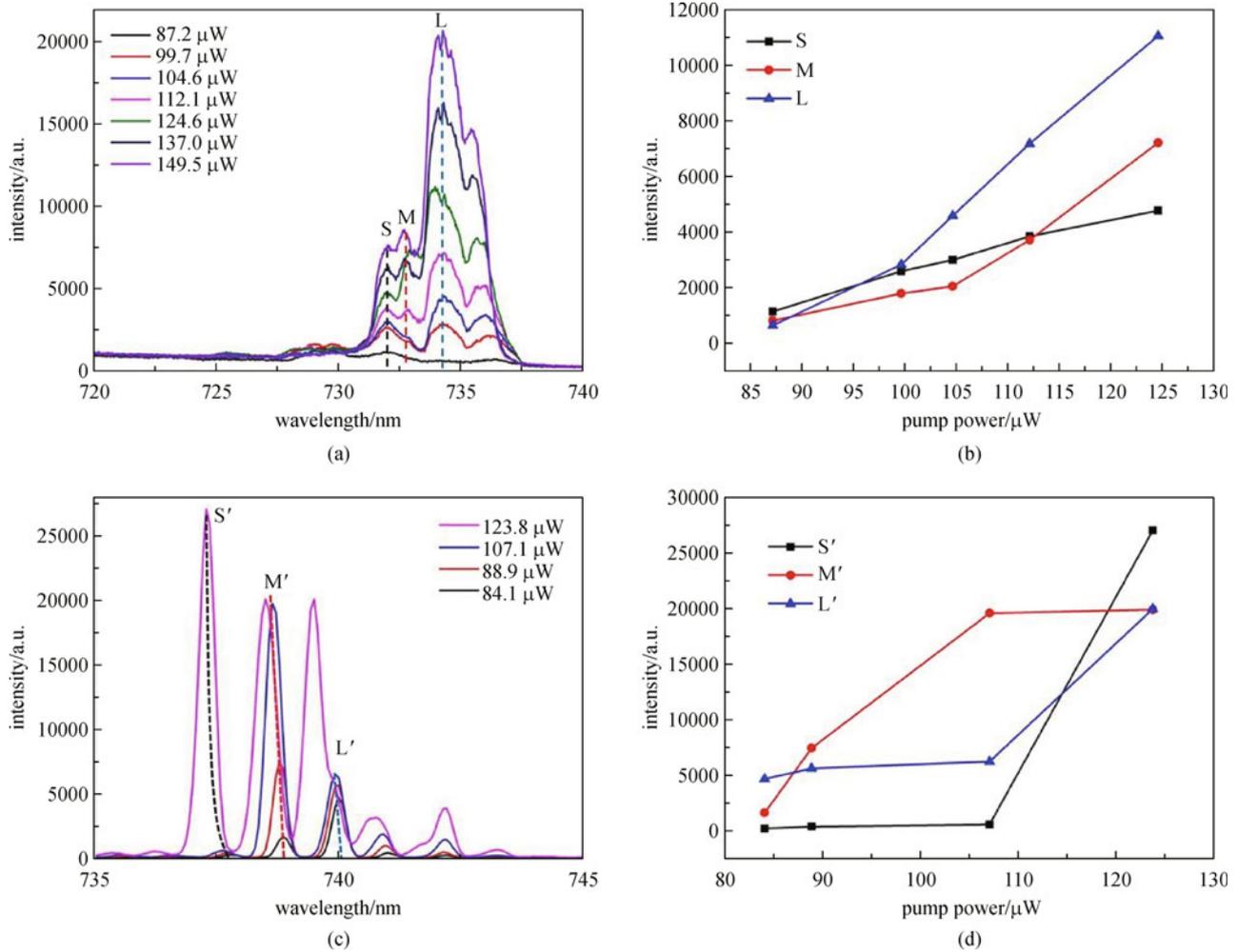


Fig. 4 (a) Pump power dependent spectra for a straight CdSe NW. S stands for short wavelength mode, M stands for middle wavelength mode and L for long wavelength mode; (b) intensities of three individual modes (S, M, L) versus pump power; (c) pump power dependent spectra for a curved NW, S' stands for short wavelength mode, M' stands for middle wavelength mode and L' for long wavelength mode; (d) intensities of three individual modes (S', M', L') versus pump power

phenomenon is discovered. We also pick three individual modes (S', M', L') to describe the change of dominant peaks with the increase of pump power, as shown in Fig. 4(c). We can see this abnormal characteristic in Fig. 4(d): the dominant peak switches from L' mode to S' mode as the pump power increases. The switching trend of curved NWs is opposite to that of straight NWs, which can be explained by the fact that the modes at longer wavelength suffer more bending loss and have a greater chance to leak away. To our best knowledge, such behavior has not been reported in previous works. Additionally, for individual lasing peaks in Figs. 4(a) and 4(c), owing to the frequency pulling effect, we can find that the wavelength of each single mode (S, M, L and S', M', L') exhibits blue-shift behavior when the pump power increases [10].

4 Conclusions

We have reported lasing characteristics of bent CdSe NWs. The red-shift can be observed much more easily and clearly in laser spectra than that in PL, indicating that laser of bent NWs could offer a more efficient approach to study the band structure change under strain. Also, the multiple times amplification of bending loss of laser predicts a more sensitive method to measure the perturbation of light induced by fairly small deformation or strain. Finally, we reported and explained the abnormal dominant peaks' switching trend in curved NW lasers. These characteristics may contribute a lot to the constructions of nanoscale laser world and deserve further investigations.

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