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Room temperature lasing characteristics in metal-coated GaN spiral and grating structures

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Abstract

We demonstrated a metal-coated GaN spiral structure lasing at room temperature with the threshold power density of 0.017 kW/cm2 under circularly polarized pumping condition. The emission wavelength is approximately 363 nm. This phenomenon could be attributed to the surface plasmon polaritons.

1. Introduction

In recent years, there are some researches about metamaterials or metasurfaces such as negative refraction [1], extraordinary transmission [2], cloaking [3], and quarter-wave plates [4]. The novel electromagnetic phenomena and the special optical properties of these metallic nanostructures could be attributed to the surface plasmonic effect. One of the most significant phenomena is the plasmonic chirality which can control the right- (R-) and left- (L-) handedness for different applications.

Recently, the surface plasmonic effect is also utilized in the metal-coated nanocavities for the stronger optical confinement and the smaller mode volume to make the scale of laser become subwavelength. In our previous work [5], we demonstrated an optical pumping metal-coated GaN grating laser at room temperature. The emission wavelength is in UV region and the polarization of the laser light from the grating is linearly polarized. For different kind of applications in the future, a circularly polarized and smaller volume nanolaser would be needed.

As we know, although the simplest device to make any light source become circularly polarized is the quarter waveplate, it is still expensive and not practical if we shrink our laser to nano scale. By combining the advantages of plasmonic chirality nanostructures like spiral type structure and the metal-coated semiconductor laser, we can not only obtain a smaller volume laser but also make the emission laser become circularly polarized possible. Therefore, in this study, we demonstrated lasing in metal-coated GaN by spiral structure at room temperature under optical pumping conditions.

2. General Instructions

The schematic diagram is shown in Fig.1 (a). The gain medium of the GaN spiral structure laser was a 2 μm thick undoped GaN layer, which is grown on a c-plane (0001) sapphire substrate by metal-organic chemical vapor deposition (MOCVD) technique. Then, the 300 nm thick Si3N4 was deposited on the planed GaN as an etching mask by plasma-enhanced chemical vapor deposition (PECVD). After that, we coated a 250 nm polymethylmethacrylate (PMMA) on Si3N4 by spin-coating method. We define the spiral pattern on the PMMA layer by E-beam lithography, then using reactive ion etching (RIE) with CHF3 /O2 mixture to etch down to the Si3N4 layer. After that, we transfer the spiral pattern from Si3N4 layer to the undoped GaN layer with about 500 nm depth by inductively coupled plasma reactive ion etching (ICP-RIE) with Cl2 /Ar mixture. The Si3N4 mask layers were removed by wet etching after all above processes. To improve the quality factor of the device, we deposit 30 nm Si3N4 layer on the patterned GaN layer. Next, a 50 nm aluminum layer was coated on the device by E-gun evaporation to form the spiral structure of metal-coated GaN laser. Fig.1 (b) showed the SEM image of the GaN spiral structure after the deposition of metal. The diameter of the spiral structure is about 20μm. The period, width and the height of the spiral structure is about 1000 nm, 400 nm and 500 nm respectively.

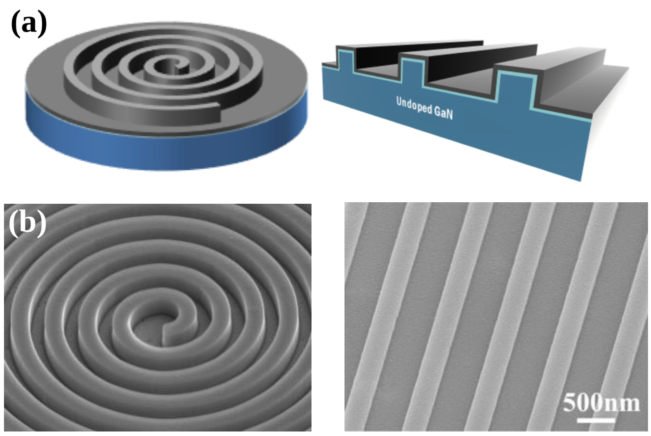

Fig. 1 (a) Schematic diagram of the metal-coated GaN spiral and grating structure. (b) The SEM image of the GaN spiral and grating structure after the deposition of metal.

The metal-coated GaN spiral structures were optically pumped by a frequency-tripled Nd: YVO4 355 nm pulsed laser at room temperature with a pulsed width of 0.5 ns and a repetition rate of 1 kHz. The diameter of laser spot size is approximately 30 μm, which could cover the device completely. A 100× objective lens was used to collect the lasing signal from the spiral structure through a multimode fiber, and coupled into a spectrometer with the charge-coupled device detectors. We directly pumped the sample from the device top to avoid the huge absorption from undoped bulk

GaN layer beneath the spiral structure, even though the metal layer might also reflect and absorb the pumping power.

Fig. 2(a) shows the measured spectra from a metal-coated GaN spiral structure above (red) and below (black) threshold under room temperature. A lasing peak wavelength around 363 nm is observed in the experiment. The light-in and light-out curve of the lasing mode and the linewidth of the spiral laser were shown in Fig. 2(b). The linear behavior after the threshold confirmed its lasing behavior, and the threshold power density was about 0.017kW/cm2. Moreover, the narrowing linewidth also proved the lasing action in the metal-coated GaN spiral laser.

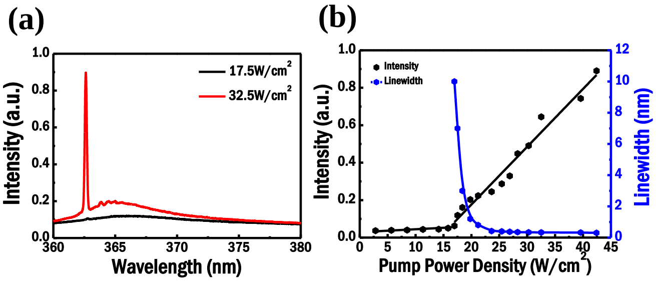

Fig. 2 (a) Measured spectra from a metal-coated GaN laser by spiral structure below (black) and above (red) threshold, lasing wavelength of the lasing wavelength of the spiral laser is 363 nm; (b) The Light-in and Light-out curve (L-L curve) from metal-coated GaN spiral laser.

To make sure whether the circularly polarized laser can significantly stimulate the metal-coated GaN spiral structure, we place a 355 nm quarter waveplate in the path of pumping laser to produce a circularly polarized laser light. Therefore, we can control the polarization of the pumping laser to be linearly or circularly polarized by linear polarizer or quarter waveplate. Fig.3 (a) shows the light-in and light-out curve of spiral structure under different polarized pumping condition. The metal-coated GaN spiral structure has a lower threshold pump power density about 0.017kW/cm2 when the pumping polarization is circular polarized. Furthermore, as shown in Fig.3 (b), we can find that the metal coated grating structure has a lower threshold pump power density about 0.016kW/cm2 when we use linear polarized pumping laser. On one hand, this phenomenon indicates that the threshold of the metal-coated GaN nanolaser depends on the type of structure if we use different polarized pumping source. On the other, Fig.3 (a), (b) also indirectly prove the metal-coated spiral structure exist a plasmonic circular polarized mode while the grating structure is easy to lase with linear polarized mode.

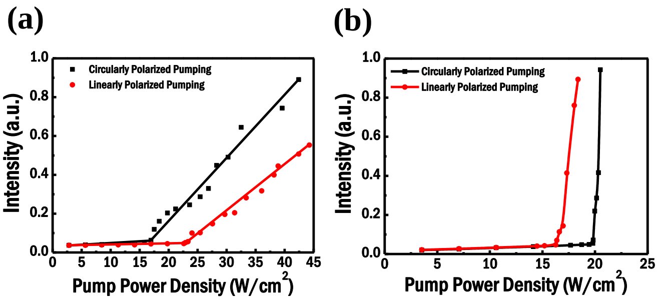

Fig. 3 The Light-in and Light-out curve (L-L curve) under different polarized pumping condition of (a)metal-coated GaN spiral structure; (b)metal-coated GaN grating structure.

3. Conclusions

In the conclusion, we successfully demonstrate metal-coated GaN spiral laser with the lasing wavelength around 363nm at room temperature. The period, width and height of the metal-coated GaN spiral structure are 1000nm, 400nm and 500nm respectively. Compared with the metal-coated grating laser, the spiral type structure has a lower threshold under circular polarized condition. This phenomenon implies that the spiral type metal-coated nano laser exist a circular polarized mode. We believe that the metal-coated GaN spiral laser would be a small volume and more practical circularly polarized laser in the future.

Acknowledgements

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