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High circular dichroism lasing characteristics in metal-GaN spiral cavity at room temperature

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Abstract

The metal-GaN spiral cavity laser with the high circular dichroism was demonstrated at room temperature. The lasing action was observed at a ultra-violet wavelength of approximately 363 nm with a low threshold power density. The high dissymmetry factor +1.4 of the metal spiral cavity lasers was observed in experiment.

1. Introduction

In recent years, circularly polarized light have attracted considerable attention in photonic technologies and future display, including optical spintronics [1], quantum-based optical information processing and communication [2], and backlights of high efficiency LCD [3]. Moreover, the circularly polarized light also plays an important role in circular dichroism (CD) spectroscopy [4]. Various researchers have investigated spiral circular polarized light-emitting devices. In 2014, Maksimov established spiral spatially-structured planar semiconductor microcavities [5]. In 2015, Marco Esposito et al. demonstrated the 3-D spiral plasmonic helices nanostructures had a g_e factor of approximately +0.74 [6]. Therefore, the circularly polarized light source is very important that many groups are interesting in constructing circularly polarized light emitting devices. However, to fabricate the ultrathin device, it is quite difficult and complex to combine the light emitting device and additional passive optical components like circular polarizer for the circularly polarized output. For this reason, the direct generation of circularly polarized light is favorable to be employed in terms of simplicity, compactness, energy efficiency and product cost. In addition, the surface plasmon effect is also utilized in the metal-cavities for the stronger optical confinement and the smaller mode volume to make the scale of laser become subwavelength. In our previous work [7], the metal-coated GaN grating laser is demonstrated by optical pumping and 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.

To utilize the many advantages of a metal- cavity, the size of a semiconductor laser can be reduced to a subwavelength scale. Although a linear polarizer and quarter-wave plate are the simplest components that enable any light source to become circularly polarized, using these components remains complex and impractical when the device is reduced to a nanoscale size.

Therefore, by combining the polarization conversion characteristic of spiral nanostructures with a metal-cavity semiconductor laser, we can obtain a laser featuring a small volume and enable the emission laser light to become circularly polarized with the highest dissymmetry factor possible. In this study, the lasing action of the metal-GaN cavity GaN was achieved around ultra-violet wavelength at room temperature.

2. Results and Discussion

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 Si_3N_4 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 Si_3N_4 by spin-coating method. We define the spiral pattern on the PMMA layer by E-beam lithography, then using reactive ion etching (RIE) with CHF_3/O_2 mixture to etch down to the Si_3N_4 layer. After that, we transfer the spiral pattern from Si_3N_4 layer to the undoped GaN layer with about 500 nm depth by inductively coupled plasma reactive ion etching (ICP-RIE) with Cl_2/Ar mixture. The Si_3N_4 mask layers were removed by wet etching after all above processes. To improve the quality factor of the device, we deposit 30 nm Si_3N_4 layer on the patterned GaN layer. Next, a 50 nm aluminum layer was coated on the device to form the spiral structure of metal-GaN spiral cavity laser. Fig.1 (b) showed the SEM image of the GaN spiral structure after the deposition of metal. The diameter of the ten circle spiral structure is about 20 μm. The period, width and the height of the spiral structure is about 1000 nm, 400 nm and 500 nm respectively.

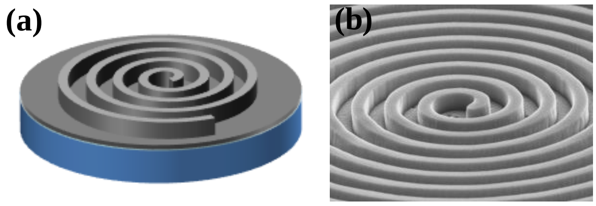

Fig.1 (a) Schematic diagram of the metal-GaN spiral cavity. (b) The SEM image of the GaN spiral structure after the deposition of metal.

To measure the lasing characteristics of the devices, the metal-GaN spiral cavities were optically pumped using a frequency-tripled Nd:YVO_4 355 nm pulsed laser at room temperature with a pulsed width of 0.5 ns and a repetition rate of 1 kHz. The spot size of the normally incident beam was approximately 30 μm, which could cover the spiral cavity completely. A 100× objective lens was used to collect the lasing signal from the metal cavity GaN spiral structure through a multimode fiber and coupled into a spectrometer with a charge-coupled device (CCD) detector.

Fig. 2(a) shows the photoluminescence spectra from a metal-GaN spiral cavity above (red) and below (blue) threshold at 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 are shown in Fig. 2(b). The threshold power density was about 0.017 kW/cm^2. Moreover, the narrowing linewidth verified that the emission photons in the cavity were converted from spontaneous emission to stimulated emission. These phenomena evidenced that the metal-GaN spiral cavity exhibited lasing action at room temperature.

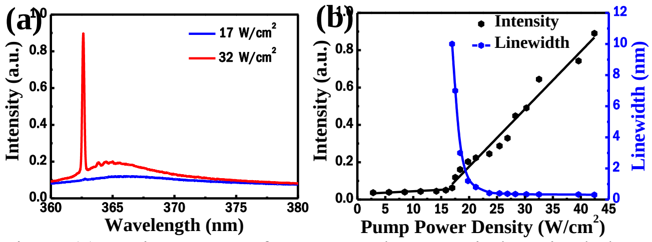

Fig. 2 (a) Lasing spectra from a metal-GaN spiral cavity below (blue) and above (red) threshold, lasing wavelength of the lasing wavelength of the spiral laser is 363 nm; (b) The Light-in and Light-out curve (L-L curve) from metal-GaN spiral cavity laser.

To define the polarization characteristics of the metal-GaN spiral cavity laser, μ-PL measurement setup is modified by adding a circularly polarized analyzer and attempted to measure the circular polarized emitter. The degree of the circularly polarized photoluminescence (CP-PL) is an essential value that can be used to determine whether a circularly polarized light is pure. The dissymmetry factor, g_e, is a value that can be used to measure the degree of CP-PL and is defined as

$$g_e = 2(I_L - I_R)/(I_L + I_R) \qquad [8]$$

Therefore, comparing the intensity difference of these two linear polarization components, the polarization state of the emission laser is RCP-like or LCP-like. Thus, I_R and I_L of the emission light is measured, the dissymmetry factor g_e can also be calculated. In the experiment, the calculated dissymmetry factors (g_e) of the spiral laser was approximately +1.4 after measuring the I_L and I_R of the spiral structures. This value of the g_e factor (+1.4) are close to the theoretical of pure circular polarized light (+2). Therefore, the metal-GaN spiral nanolaser can potentially offering a room temperature circular polarized UV nanolasers for optical information technologies, chip-scale integrated circuits and biological applications.

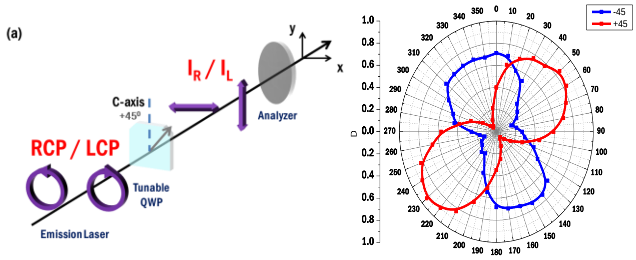

Fig. 3 Polarization degree of perpendicular and horizontal linear polarization light converted from the spiral laser.

3. Conclusions

In conclusion, a room temperature metal-GaN spiral laser is demonstrated. The lasing wavelength of the spiral laser was approximately 363 nm, and the pretty high dissymmetry factors of the metal-GaN spiral laser was approximately +1.4 with the low threshold pump power densities was 0.017 kW/cm^2.

Acknowledgements

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