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Circular Polarized Lasing Characteristics in Metal/GaN Double-Spiral Cavity Laser at Room Temperature

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Abstract

The high circular polarized laser was demonstrated with a compact metal/GaN double-spiral cavity at room temperature. The lasing action was observed at 363 nm ultraviolet wavelength with a low threshold power density. The high dissymmetry factors (g_e) of the left-handed double-spiral metal cavity lasers were approximately +1.6 (+2 pure left-handed circular polarized) which is a decent high CD value compared with the reported values from the artificial metamaterials and directly circularly polarized light emitters.

1. Introduction

Recently, circularly polarized light has attracted considerable attention due to the wide practical applications such as circular dichroism (CD) spectroscopy, which can be applied to analyze molecules with optical activity [1], chiral synthesis [2] in biology and chemistry, and ultrafast magnetization control [3]. Therefore, researchers in many fields are interested in constructing circularly polarized light-emitting devices.

Several groups have studied circularly polarized light-emitting devices with the spiral. Konishi et al. (2011) showed that semiconductor planar spiral nanostructures had a g_e of about −0.528 [4]. Maksimov et al. (2014) demonstrated semiconductor planar spiral-structured microcavities with g_e around +1.04 and −0.94 [5]. Compared with the CD of previously reported structures, the metal/GaN double-spiral cavities exhibited the even higher CD with a single-wavelength output and small footprint for a light source with the high circular polarization. It could be controlled precisely and effective than the broad band light emitters for chip-scale integrated circuit application.

2. Experiment

The schematic diagram is shown in Fig.1 (a). The gain medium of the metal/GaN cavity 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, and then reactive ion etching (RIE) with CHF_3/O_2 mixture was applied 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 by E-gun evaporation to form the double-spiral metal cavity. Fig.1 (b) showed the SEM image of the metal/GaN left-handed double-spiral cavity. The radius of the left-handed double-spiral metal cavity is approximately 10 μm. The period, width and the height of the double-spiral is about 1000 nm, 300 nm and 500 nm respectively.

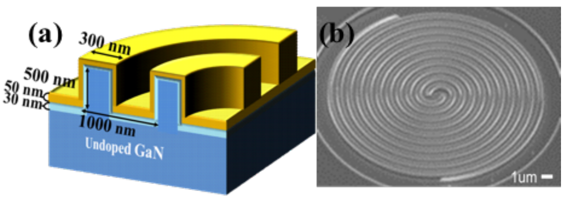

Fig. 1 (a) Schematic diagram of the metal/GaN double-spiral cavity. (b) The SEM image of the metal/GaN left-handed double-spiral cavity.

The metal/GaN double-spiral cavity was optically pumped by 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 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 double-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 shows the measured spectra from a metal/GaN double-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 were shown in Inset of Fig. 2. The linear behavior after the threshold confirmed its lasing behavior, and the threshold power density was about 0.028

kW/cm^2. Moreover, the narrowing linewidth also proved the lasing action in the GaN double-spiral nanolaser.

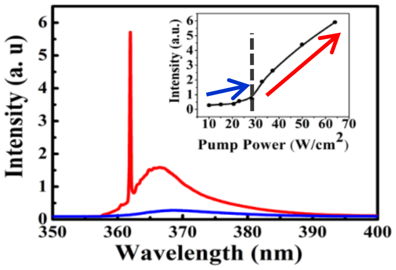

Fig. 2 Measured spectra from a metal/GaN double-spiral cavity laser below (blue) and above (red) threshold, lasing wavelength of the lasing wavelength of the double-spiral laser is about 363 nm. Inset: The Corresponding Light-in and Light-out curve (L-L curve)

To investigate the polarization characteristics of the metal/GaN double-spiral laser, we modified the μ-PL measurement setup by adding a circularly polarized analyzer and attempted to distinguish the polarization difference in the emission laser between the double-spiral metal cavity. In this study, we combined a tunable quarter-wave plate, in which the λ/4 phase retardation can be tuned to various wavelength (from 150 nm to 6 μm), and a linear polarizer within the UV region to construct a circularly polarized analyzer for distinguishing the polarization state of our spiral lasers. Fig. 3 showed the tunable quarter-wave plate setting for the 363 nm region in which the c-axis is at +45° with respect to the vertical direction (z-axis) that separates the RCP from LCP through polarization conversion. After passing through the circular polarized filter, the measured horizontal component (x-axis) of the linear polarization represents the intensity of RCP light, denoted as I_R, whereas the perpendicular component (y-axis) of the linear polarization indicates the intensity of LCP light, denoted as I_L. Therefore, by comparing the intensity difference of these two linear polarization components, we can assess whether the polarization state of the emission laser is RCP-like or LCP-like. Once we measure the I_R and I_L of the emission light, the dissymmetry factor g_e is shown as below as eq. (1)

$$g_e = 2\left(\frac{I_L - I_R}{I_L + I_R}\right) \qquad (1)$$

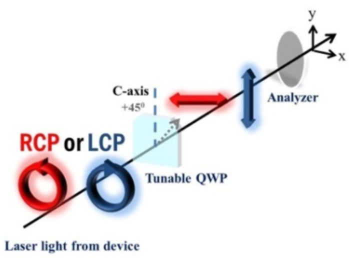

Fig. 3 Schematic diagram of the circularly polarized analyzer that can separate the LCP and RCP light by assessing the direction of the linear polarization converted by the tunable quarter-wave plate.

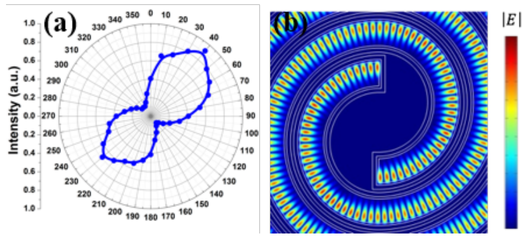

Fig. 4 (a) Dissymmetry factors (g_e) measured results of metal/GaN double-spiral cavity laser. (b) Simulated mode profile of double-spiral metal cavity.

Fig. 4(a) shows the polarization curve of the lasing signal after the quarter-wave plate and linear polarizer. It confirmed that the double-spiral metal cavity could produce LCP laser signal with high circular polarized state. This value of the g_e factor (+1.6) is close to the theoretical pure left-handed circular polarized light (+2). Fig. 4(b) shows the calculated lasing mode in the metal/GaN double spiral cavity with the finite-element method (FEM). The high quality mode shows the excellent optical confinement in the metal cavity.

3. Conclusions

In short, the higher circular polarized single UV wavelength laser was demonstrated with a smaller footprint metal/GaN double-spiral cavity at room temperature. A high dissymmetry factor of +1.6 was observed from this metal/GaN double-spiral laser. This work realizing simple, compact, and energy-efficient devices at low cost and potentially offering a compact circular polarized UV laser for optical information technologies, chip-scale integrated circuit and biological applications.

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References

[1] P. Atkins and J. Paula, Elements of Physical Chemistry.: (Oxford University Press, New York, USA, 2005)

[2] Rau H, Chemical Reviews. 83, 535-547 (1983)

[3] H. Krenn, W. Zawadzki and G. Bauer, Physical Review Letters. 55, 1510 (1985)

[4] K. Konishi, M. Nomura, N. Kumagai, S. Iwamoto, Y. Arakawa and M. Kuwata-Gonokami, Physical Review Letters. 106, 057402 (2011)

[5] A. A. Maksimov, I. I. Tartakovskii, E. V. Filatov, S. V. Lobanov, N. A. Gippius, S. G. Tikhodeev, C. Schneider, M. Kamp, S. Maier, S. Höfling, and V. D. Kulakovskii, Physical Review B. 89, 045316 (2014)

[6] R. Farshchi, M. Ramsteiner, J. Herfort, A. Tahraoui and H. Grahn, Applied Physics Letters. 98, 162508 (2011)

[7] M. Esposito, V. Tasco, F. Todisco, M. Cuscunà, A. Benedetti, D. Sanvitto, A. Passaseo, Nature Communication. vol. 10, pp. 1038–1319 (2015)