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Research on the special-shaped microdisk with the cone angle of the whispering gallery mode with directional emission

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Abstract

In this paper, we propose and study a GaN material-based echelle wall mode shaped microdisk, which achieves the directional emission of the microdisk by breaking the rotational symmetry of the disk. Using finite element analysis method to systematically analyze the outgoing intensity of the tapered-angle microdisk, the optimal taper angle parameters are selected to construct the tapered-angle microdisk, and a single longitudinal mode outgoing with a Q value of about 2100 near the resonant peak wavelength of 341 nm is achieved. This structure provides a new idea for shaped microcavities in the field of unidirectional emission, and it is beneficial to promote the development of low-threshold lasers and high-sensitivity sensors, which have certain research value and application prospects in the fields of optical communication and environmental detection.

Keywords

Laser optics; whispering gallery mode; cone angle microcavity; directional emission; finite element analysis method.

1. Introduction

Optical microcavity is a kind of miniature optical resonator that can confine the light field in the cavity for a long time. By using the total reflection effect of light on the inner surface of the microcavity [1-5], the light can form a stable residence in the narrow cavity. wave oscillation. Optical microcavity has gradually become a hot spot in the field of optical research, and the whispering gallery mode (WGM) optical microcavity has a very high quality factor (Q value) and a very low mode volume, which has become an important research direction in the field of optical microcavity. [6, 7], it has been widely used in sensors, low-threshold lasers, filters, optical amplifiers, optical memory and other fields [8].

In this paper, a special-shaped microdisk is studied. By breaking the rotational symmetry of the traditional circular microdisk, the directional output with a high Q value is realized, and the directional output with a Q value of about 2100 is realized. This structure not only expands the research scope of hetero-shaped microcavity in the field of directional emission, but also facilitates the development of low-threshold lasers and optical communications.

2. Device design

For traditional circular microdisks, most of the photons cannot escape outside the microdisk, resulting in poor exit direction and low efficiency. In this paper, the symmetry of the disk is broken (as shown in Figure 1(a)), and most of the photons are bound in the cavity by using the total reflection effect of the circular structure, thereby maintaining a high quality factor; then the photon orientation is solved by introducing an asymmetric structure Exit problem. For any material with refractive index n>1, the light entering the microdisk will exit along the cone angle, as shown by the blue solid line in Fig. 1(a). Due to the high integration, low threshold and low power consumption of semiconductor devices made of GaN materials, they are widely used in the fields of integrated optics and new optoelectronic devices. The refractive index under transverse electrical mode (TE) polarization of the cone-angle microdisk is expressed by Sellmer's dispersion equation:

$$n^2=3.60+\frac{1.75\lambda^2}{\lambda^2-0.256^2}+\frac{4.1\lambda^2}{\lambda^2-17.86^2} \tag{1}$$

Where, n is the refractive index of the GaN material at wavelength λ.

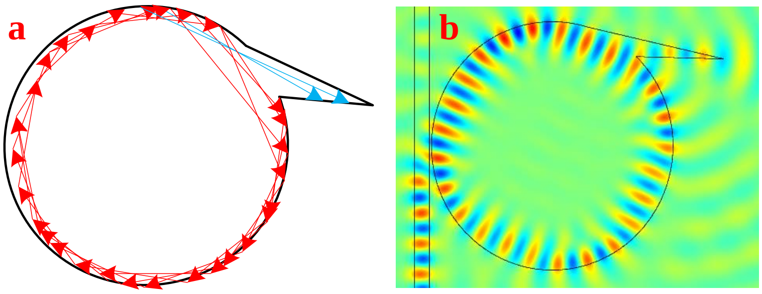

Fig.1 Schematic diagram of the whispering gallery of the cone angle microcavity

Q value is an important parameter used to measure the speed of energy attenuation in optical micro-cavity loss, and its definition is as follows:

$$Q=\omega\frac{U}{P}=\omega\frac{U}{-dU/dt}=\omega\tau_0 \tag{2}$$

Where, U is the total energy stored in the micro-cavity, $P=-dU/dt$ is the lost power, ω is the frequency of the light field, and τ_0 is the average lifetime of the photons in the cavity. Therefore, a higher Q value means that the micro-cavity has a stronger binding ability to the photons in the cavity . Theoretically, the following three inherent losses should be considered in an optical microcavity: material loss (Q_{mat}), radiation loss (Q_{rad}) and surface scattering loss (Q_{scatt}):

$$\frac{1}{Q}=\frac{1}{Q_{mat}}+\frac{1}{Q_{rad}}+\frac{1}{Q_{scatt}} \tag{3}$$

Where, $\frac{1}{Q_{rad}}$ is the intrinsic radiation loss of the optical microcavity mainly determined by the ratio of diameter D and resonance wavelength λ ; $\frac{1}{Q_{mat}}$ is the loss of the material itself, which is generally very small. Thus the Q value is mainly determined by the surface scattering loss $\frac{1}{Q_{scatt}}$. In addition, the Q-value of the optical microcavity can also be approximated from the output spectrum using the following equation:

$$Q=\frac{\delta\omega}{\omega}=\frac{\lambda}{\delta\lambda} \tag{4}$$

Where, ω and λ represent the resonant frequency and resonant wavelength respectively, and $\delta\lambda$ and $\delta\omega$ are the FWHM of the corresponding spectral frequency and resonant wavelength respectively.

3. Analysis and discussion

Through the above theoretical analysis, the microdisk parameters are optimized to adjust the cone Angle microdisk structure. The performance of directional ejection of a two-dimensional cone-angle disk with different cone-angle parameters is studied by means of finite element analysis. A perfect matching layer (PML) with a thickness of 1μm was used as the boundary condition for all surfaces in the calculated region. In this scheme, the light source is injected

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into the micro-nano fiber, and the acoustic wall mode is stimulated by coupling with the abnormal microdisk to find the optimal emission intensity of the abnormal microdisk.

When changing the cone angle and the size of the cut angle of the circular microdisk, the output spectrum at the cone angle is shown in Figure 2. When the chamfer angle is 43°, the cone angle is small at this time, and the microdisk has a strong ability to confine light, and only evanescent waves and a small number of photons are emitted at the cone angle; as the chamfer angle increases to 49°, the confinement A part of the photons in the cavity are emitted at the cone angle, so that the single longitudinal mode intensity of the cone angle microdisk reaches 11800V/m; when the chamfer angle is further increased to 54°, the light confinement factor of the microdisk decreases, and more photons from exit at the cone angle, resulting in a lower Q value for the microdisk. On the other hand, the interference effect that occurs at the cone angle of coherent light reduces its output intensity. To sum up, increasing the chamfering angle of the cone angle (43°~54°), the intensity of the longitudinal mode emitted at the cone angle shows a fluctuating upward trend as a whole. Too large or too small chamfering angle will affect the output longitudinal mode energy. Therefore, the chamfering angle is selected as 49° to achieve a single longitudinal mode output with a narrow half-peak waist width with an intensity of 11800V/m.

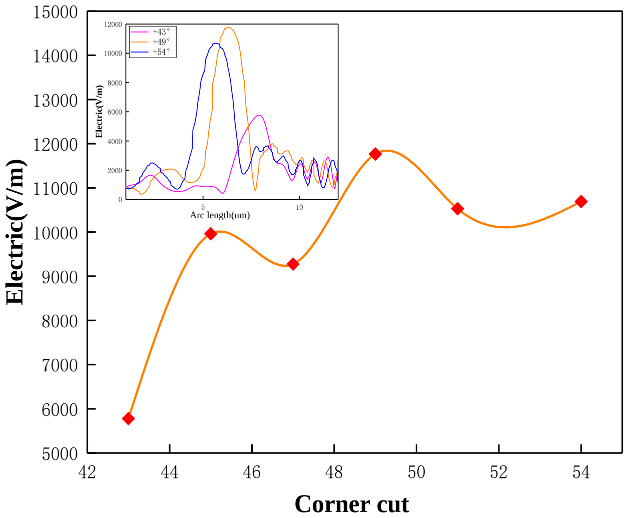

Fig. 2 Trend diagram of electric field intensity of anomalous microdisk

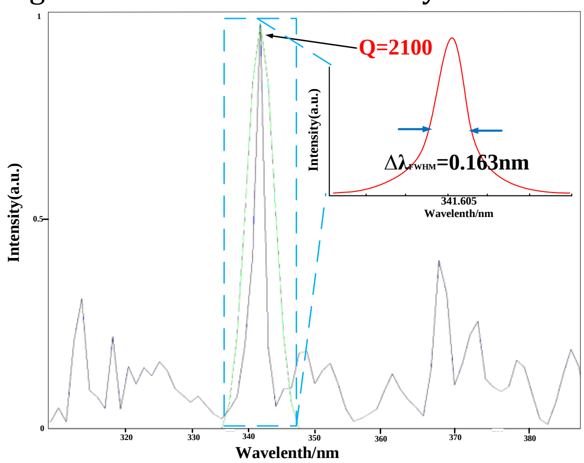

Fig 3. The output spectral response curve of the special-shaped microdisk (the inset is an enlarged view of the strongest resonance peak in the dotted rectangle)

As shown in Fig. 3, the strongest resonance peak of the cone-angle microdisk is around 341.6nm, and the waist width of the half-peak of the output spectral response curve is 0.163nm. According to Formula (4), the Q value can be calculated as 2100. Similarly, the position of the

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resonant peak can be adjusted by enlarging or reducing the size of the microdisk, and the cone Angle parameters can be optimized to achieve the best directional emission of different wavelengths.

4. Conclusion

In this paper, we study a gan-based abnormal microdisk with echo wall mode. By breaking the rotation symmetry of the circular microdisk, we realize the directional emission of high Q value of the abnormal microdisk. By finite element analysis, the best exudation strength of the profiled microdisk was found. The strongest resonant peak wavelength of the structure is 341nm, and the single longitudinal mode emission with Q value of 2100 is realized. The structure proposed in this paper provides a new idea for the research of deformable microdisks in the field of directional emission and expands the research of low-threshold lasers in the field of miniaturization.

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