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Microlaser from Self-Assembled Hemispherical Resonator

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Abstract: High quality Whispering Gallery Mode lasing from dye-doped hemispherical microresonator formed by hydrophobic effect is presented. Owing to a simple fabrication, doping flexibility, our finding boosts a convenient implementation of microlasers.

OCIS codes: (140.2050) Dye lasers; (140.3945) Microcavities; (160.5470) Polymers.

1. Introduction

A low-threshold microlaser is important because of their potential application in various fields such as photonic integrated circuits and quantum information processing. In order to achieve the low-threshold laser, the microresonator typically need has a high quality (Q) factor. However, conventional fabrication of high Q microresonators is primarily limited to semiconductor materials with either top-down or bottom-up technique [1-3], which is costly and not flexible in terms of materials choice, wavelength tuning and cavity geometries. To solve this problem, soft microcavities based on microdroplet, liquid crystal, organic polymers have attracted increasing attention in recent year, due to the simple fabrication and doping flexibility [4-6].

In this work, we report on high Q factor self-assembled flexible microresonator which demonstrates robust whispering gallery mode (WGM) lasing characteristics upon optical pumping. Moreover, the tunability of hemisphere's size allows us to study the cavity length dependent WGM lasing.

2. Fabrication

A Distributed Bragg Reflector (DBR) was used as a substrate. It consists of 27 pairs of alternating SiO₂ and TiO₂ quarter-wave layers which were deposited by electron beam evaporation. The stop-band width of DBR is about 140 nm with reflectivity of about 99.5% at 630 nm. A layer of 1H, 1H, 2H, 2H-perfluorooctyltriethoxysilane (so-called hydrophobic layer) was then deposited at the topmost layer of the DBR by spin coating. This layer increases the hydrophobic effect by surface modification [6]. In addition, a solution was used to create the hemispheres is a composition of Araldite[®] 506 epoxy resin (from Sigma-Aldrich) dissolved in chloroform solvent with a volume ratio of 8:1, and doped with 4 mM molecular Rhodamine 6G (R6G).

To fabricate the hemisphere, a small amount of solution was transferred to the DBR surface by a sharp tip and the hemisphere was self-assembly formed due to the hydrophobic effect after several minutes. As a result, the hemisphere size is tunable by the amount of solution. The obtained hemispheres then were dried in air for 24 hours and additionally at 80°C for 1 hour. Figure 1a-1d demonstrate optical images of the hemispherical structures with diameters from about 75 to 20 μm.

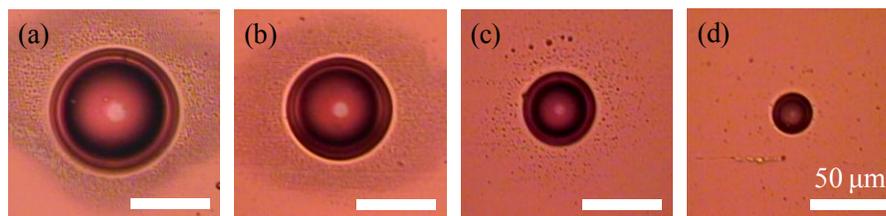


Fig.1. The top-down view optical image of hemispherical resonators with different sizes under halogen illumination.

3. Whispering Gallery Mode lasing

Optical characteristics investigation of individual hemisphere was carried out by using a micro-photoluminescence (μ -PL) system and WGM lasing was observed under pulse pumping. Figure 2a shows the pump pulse energy (PPE)-dependent μ -PL spectra of studying hemisphere at room temperature. It can be seen that the PL intensity increases as increasing the PPE of the incident laser and lasing emission was observed above PPE > 10.6 μ J. A nonlinear increase of the emission intensity confirms the lasing action, and the lasing threshold is around 10.5 μ J (Fig. 2b).

In this hybrid microresonator, light is trapped in three-dimensional (3D) due to total reflection at hemisphere-air in horizontal direction and high reflectivity of DBR in vertical direction. Therefore, emission can be enhanced by the

resonance referred to as Whispering Gallery Mode (WGM) [5, 6]. From the obtained spectra, it seems that only first order WGM occurs so we assumed the radial mode number $r = 1$. As a result, the resonant wavelength of the WGM can be calculated from following equation,

$$m = \pi D n_{eff} / \lambda_m \quad (1)$$

where m is the angular mode number, D and n_{eff} are diameter and effective refractive index of the hemisphere, respectively. The calculated n_{eff} is 1.41, assuming $D = 33.12 \mu\text{m}$, corresponding mode numbers are indexed as 259-261. These values match well with lasing peaks in Fig. 2a, which confirms the WGM lasing mechanism. Moreover, lasing characteristics of hemispheres with different sizes are shown in Fig. 2c. The free spectral range (FSR) curve follows $\lambda^2/(\pi n_{eff} D)$ function, and Q factor can reach up to about 8000 for a large hemisphere with $D = 100 \mu\text{m}$.

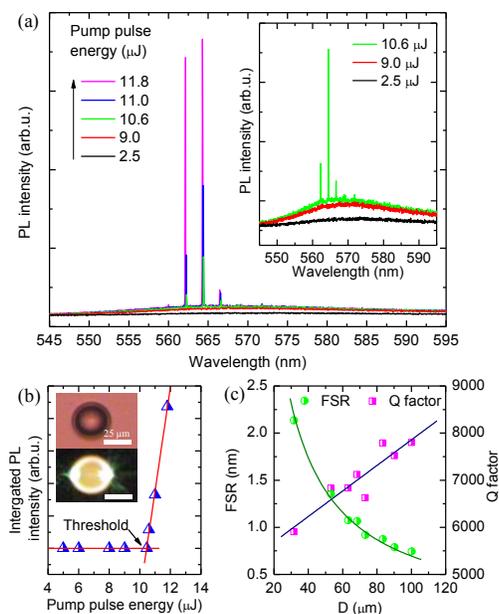


Fig.2. (a) The PL emission recorded at room temperature as a function of pump power of pulse laser. The inset shows the enlarged part of the μ -PL spectrum in the low range of excitation density. (b) The integrated PL intensity dependence on the excitation pumps power. The optical image (top) and PL image (bottom) of the hemisphere are given in the inset. (c) FSR and Q factor change with D . The FSR curve fits well to a $1/D$ function.

4. Conclusion

In conclusion, we have reported a low-cost, easily fabricated, and high quality 3D confined hemispherical microresonator. This achievement can facilitate novel applications for photonic devices as well as provide an excellent platform for fundamental studies of light-matter interaction.

5. References

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