Water-resistant $CsPbBr_3$ perovskite quantum dots embedded in polymer microfiber for WGM lasing

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Abstract

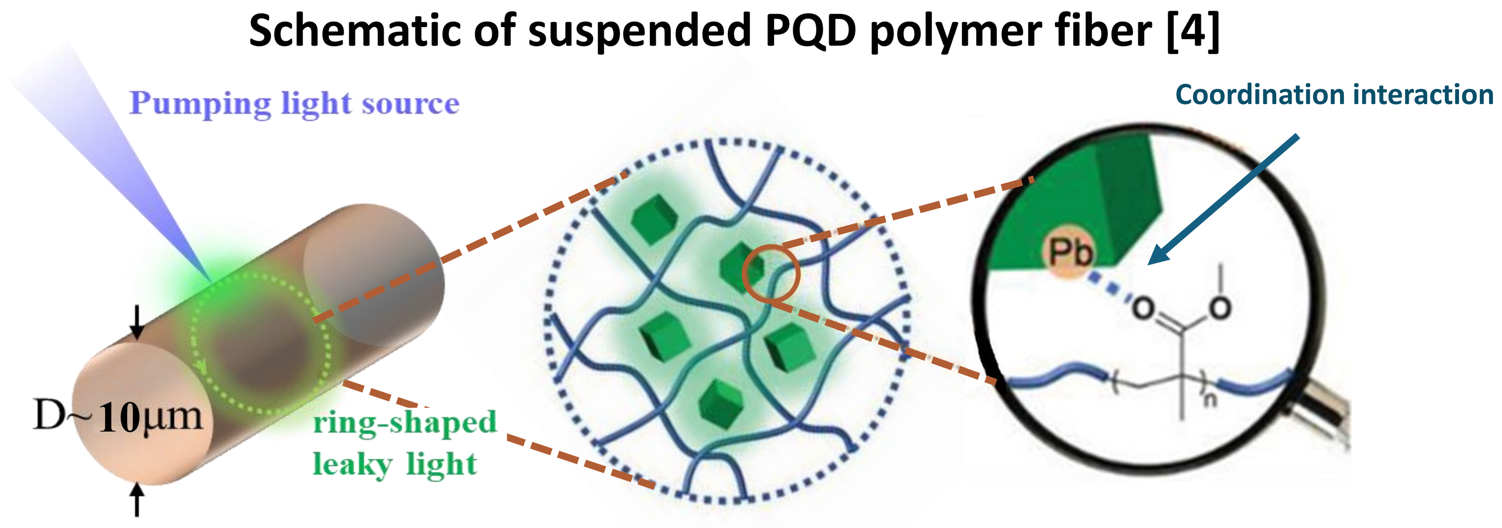
Whispering gallery mode (WGM) lasers exhibit significant potential for applications in optical communication, sensing, and photonic circuits. In this work, suspended $CsPbBr_3$ QDs polymer (PMMA) fibers were prepared as a WGM resonator using the drawing method in an ultra-low humidity environment. The fiber not only exhibited a smooth surface but also maintained long-term fluorescence performance when simultaneously exposed to water immersion. Under pulsed laser excitation, the composite demonstrated WGM lasing behavior with a threshold of 450 μJ/cm². This research explores the boundless potential of WGM resonators for advancing the next generation of optoelectronic devices.

Introduction

Perovskite quantum dots (PQDs) have been widely used in various optoelectronic devices owing to their outstanding optical gain properties [1], but perovskite crystals are sensitive to highly polar compounds and readily degrade in air. To solve their instability problem, fabricated in polymer can possess better durability and surface passivation. [2] Furthermore, a cylindrical resonator can confine light to support the formation of a Whispering Gallery Mode (WGM) [3], where light waves undergo total internal reflections within the microcavity, leading to amplified light energy. However, the vapor-induced phase separation effect often causes surface roughness, increased optical loss, and poor water stability. To address this, we use the wire drawing method to prepare the fiber under an ultralow-humidity environment. The fiber exhibits excellent water resistance characteristics and successfully demonstrate WGM lasing with a low threshold.

Material Characteristics

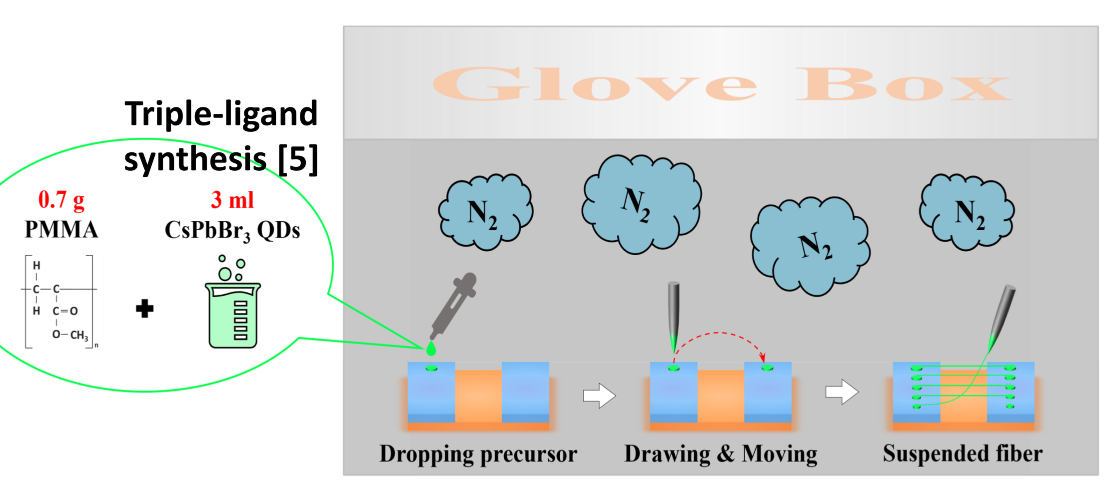
Schematic of suspended PQD polymer fiber [4]



- $CsPbBr_3$ quantum dots are embedded in polymer (PMMA) successfully.

Experiment Setup

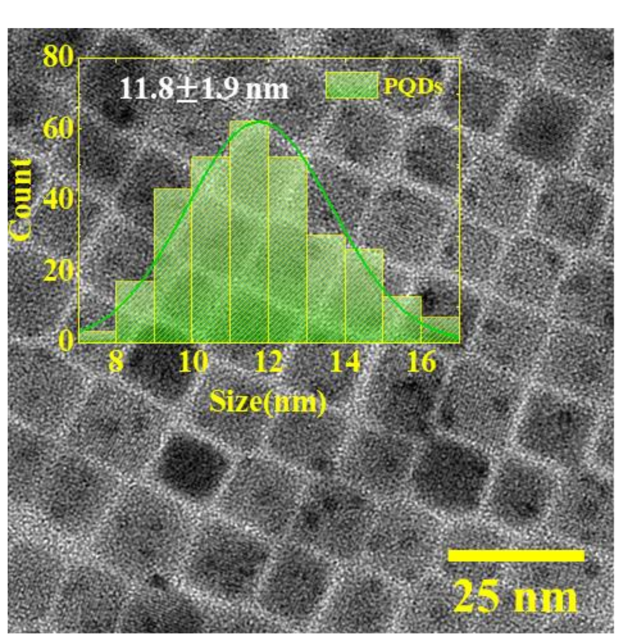
Suspended perovskite QD polymer fibers process



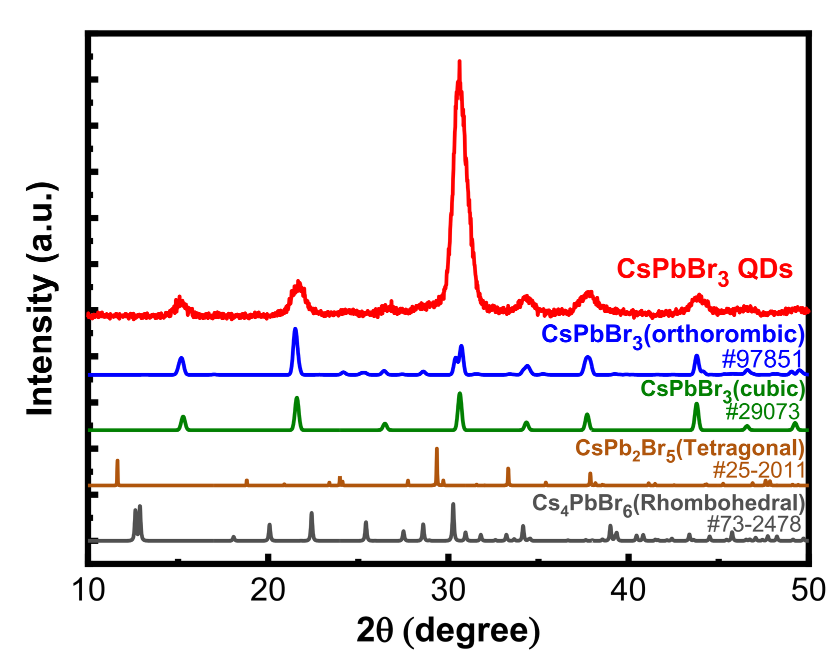
- Polymer fibers were prepared in ultralow humidity (<10 %) to reduce the VIPS effect.

PVSK QDs Properties

TEM image of PQDs

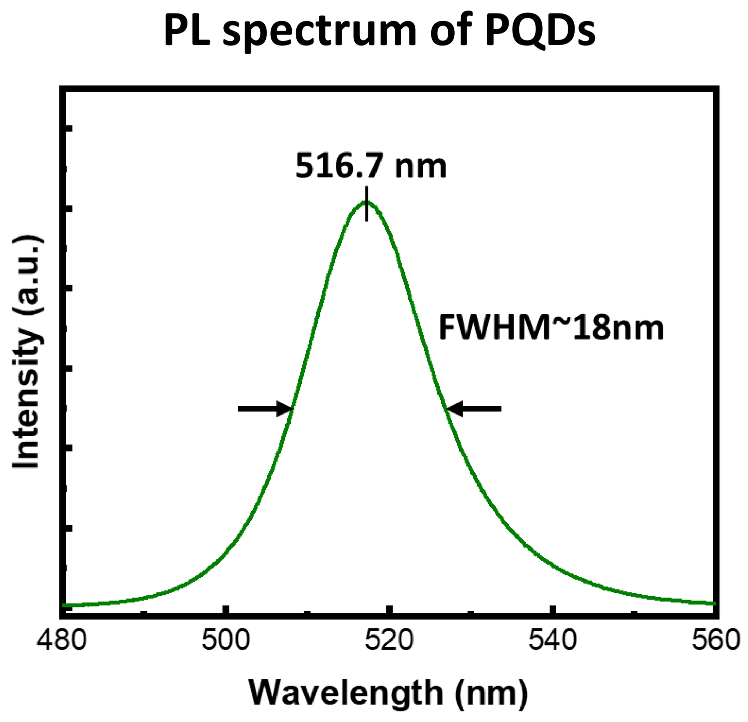


XRD analysis of PQDs

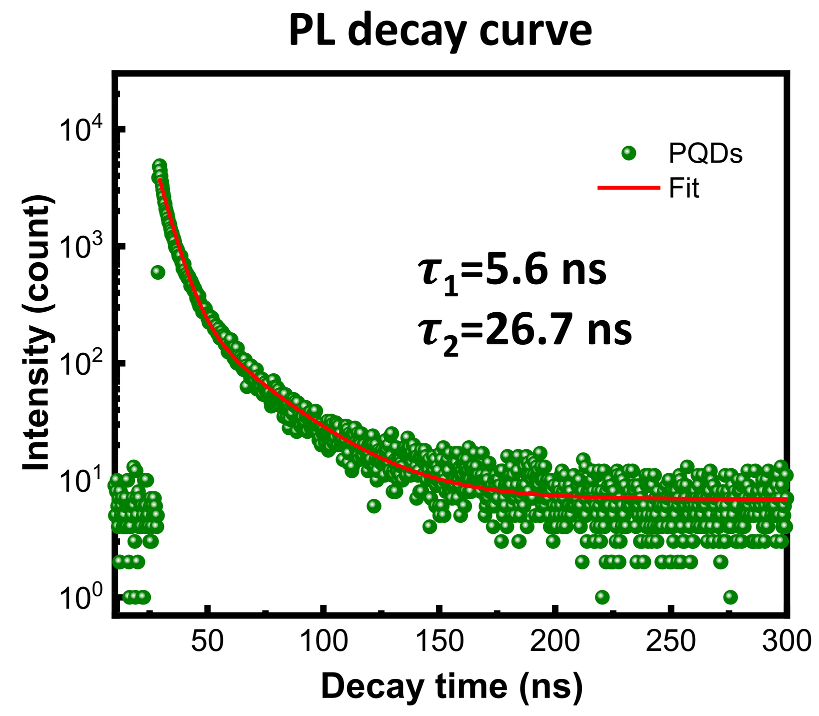


- The crystal size of PQDs is 11.8±1.9 nm.
- Through XRD analysis, the PQDs exhibit the $CsPbBr_3$ orthorhombic crystal phase rather than the $CsPb_2Br_5$ or Cs_4PbBr_6 phases.

PL spectrum of PQDs



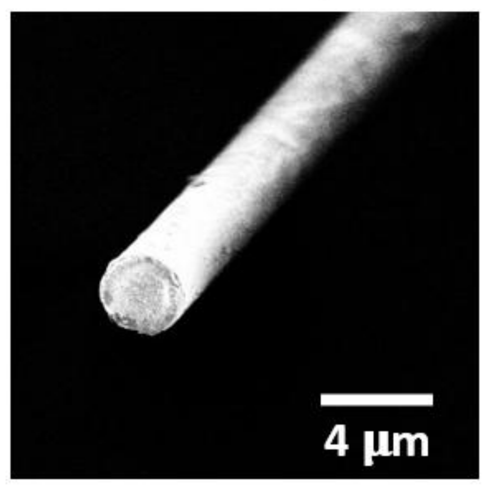
PL decay curve



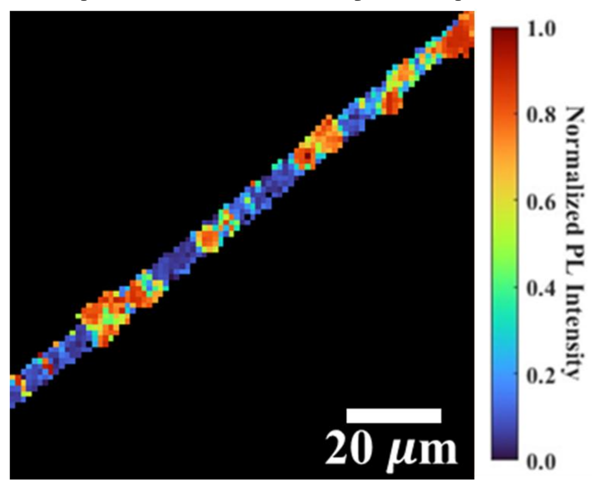
- The PQDs exhibit a narrow FWHM of 18 nm.
- The τ_1 and τ_2 are 5.6 ns and 26.7 ns, respectively. But A_1 is higher than A_2, so that are more non-radiative recombination pathways.

PVSK QDs Fiber Properties

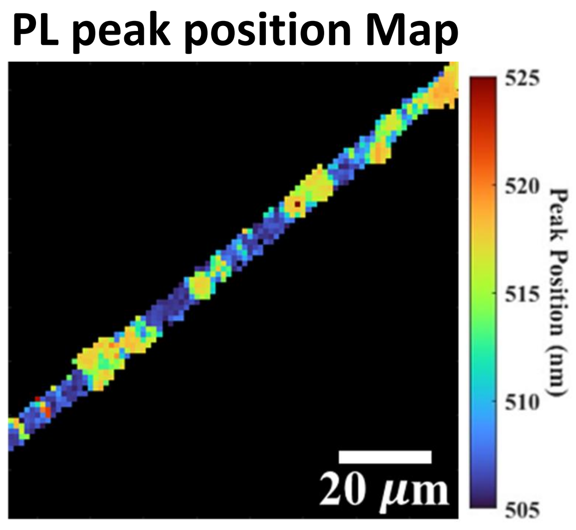
SEM image



PL peak intensity Map

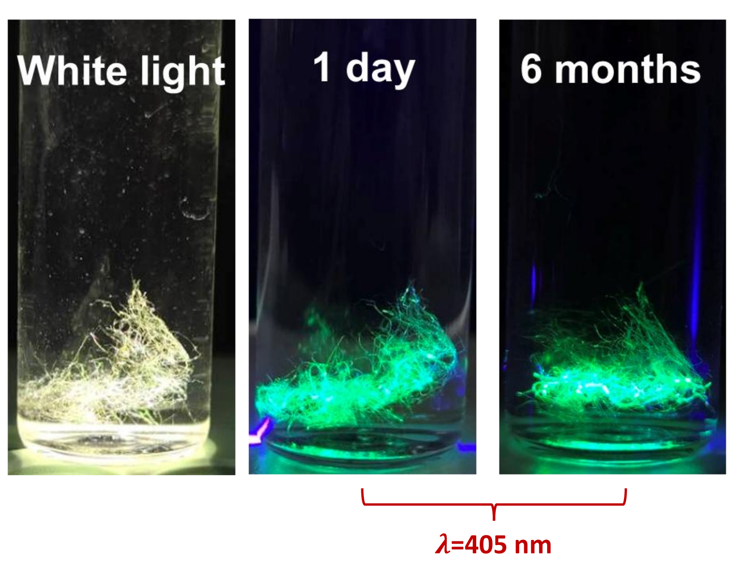


PL peak position Map

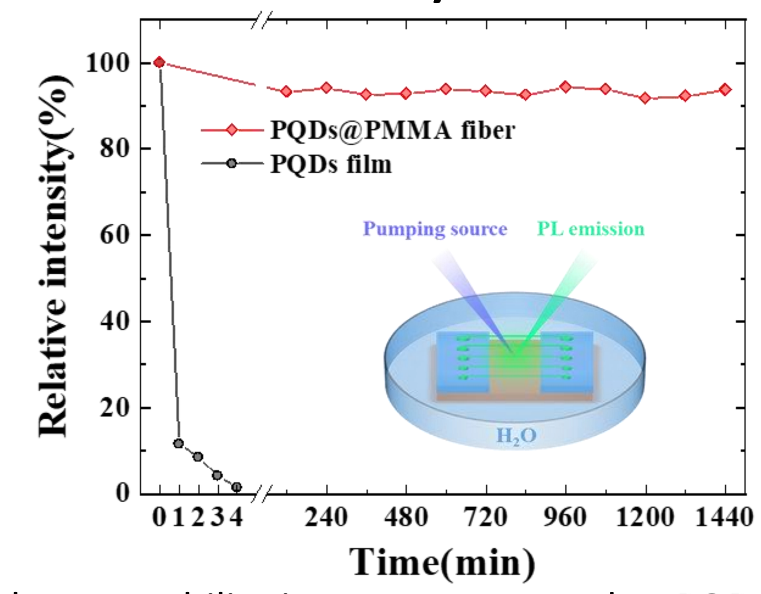


- Under PL mapping measurement, the regions with higher luminous intensity exhibit a redshifted emission wavelength.

Photograph of PQD fiber



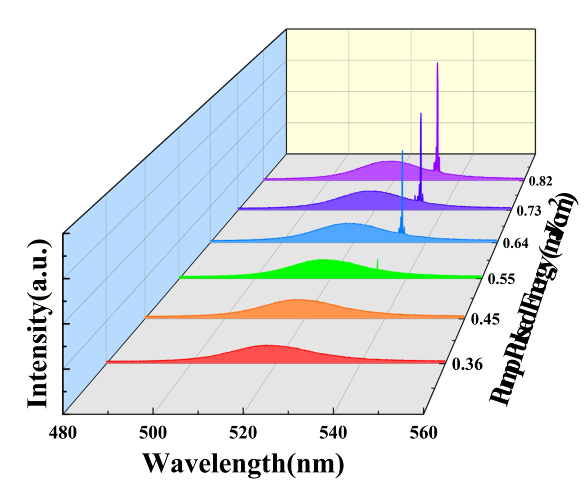
Relative intensity related to time



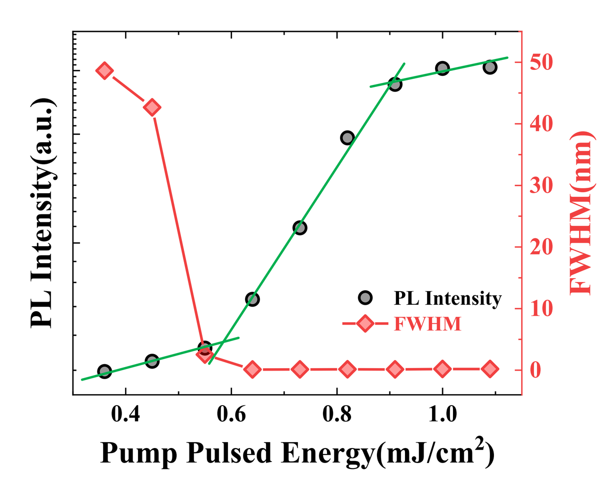
- The PQDs polymer fibers exhibit significantly better stability in water compared to PQDs thin films.

Lasing Analysis

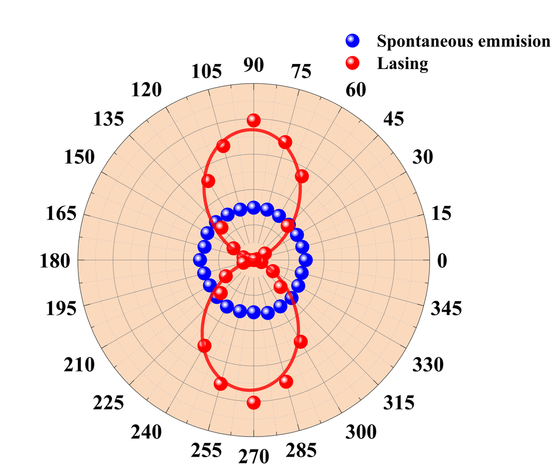
Power-dependent PL spectra



Light-in light-out curve

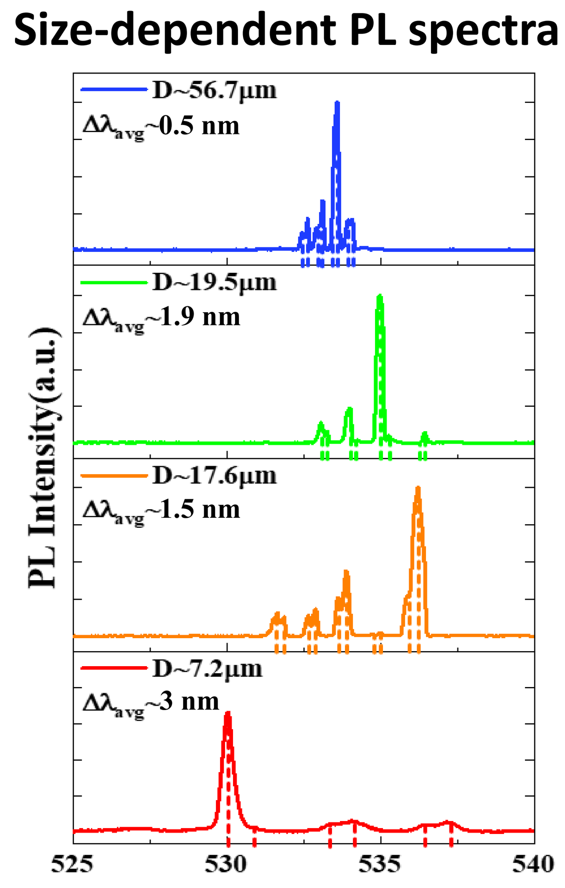


Polarization dependent

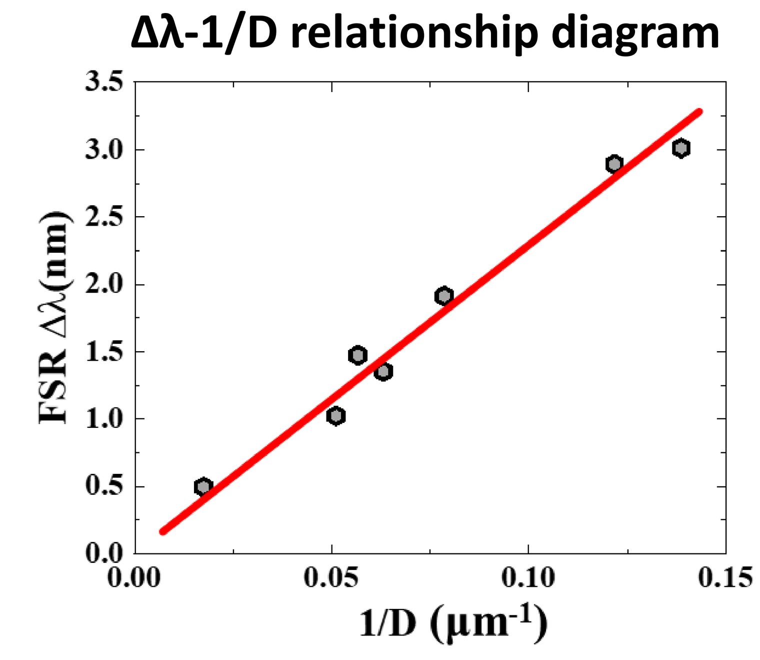


- It shows that the spectra's FWHM narrowed significantly, and the lasing threshold was determined to be 450 μJ/cm².
- Polarization-dependent could rule out the characteristics of random lasing.

Size-dependent PL spectra



Δλ-1/D relationship diagram



Free Spectral Range (FSR) relation of WGM resonators

$$D\pi = 2R\pi = \frac{m\lambda_0}{n_1} \Rightarrow \Delta\lambda \approx \frac{\lambda_0^2}{n_g D\pi} \Rightarrow \Delta\lambda \propto 1/D$$

- The mode spacings as a function of the inverse of cavity diameter.

Conclusion

We successfully prepare PVSK QD polymer fibers in an ultralow-humidity environment. The smooth surface and suspended structure of the fiber enhance the lasing performance and excellent water-resistance. The high-performance WGM resonator has great promising on sensor and photonic applications.

Reference

[1]Boehme, Simon C., et al. "Single-photon superabsorption in CsPbBr3 perovskite quantum dots." Nature Photonics (2025): 1-7.
[2] Wei, Shibo, et al. "Strongly-Confined CsPbBr3 Perovskite Quantum Dots with Ultralow Trap Density and Narrow Size Distribution for Efficient Pure-Blue Light-Emitting Diodes." Small 20.36 (2024): 2400885.
[3] Tian, Xiaoyu, et al. "Whispering gallery mode lasing from perovskite polygonal microcavities via femtosecond laser direct writing." ACS Applied Materials & Interfaces 13.14 (2021): 16952-16958.
[4]Cai, Yuting, et al. "A facile synthesis of water-resistant CsPbBr3 perovskite quantum dots loaded poly (methyl methacrylate) composite microspheres based on in situ polymerization." Advanced Optical Materials 7.22 (2019): 1901075.
[5]Song, Jizhong, et al. "Room-temperature triple-ligand surface engineering synergistically boosts ink stability, recombination dynamics, and charge injection toward EQE-11.6% perovskite QLEDs." Advanced Materials 30.30 (2018): 1800764.