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Numerical simulations and experimental observation of photonic nanojets generated by TiO_2 microparticles

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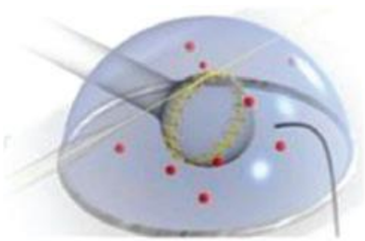
Motivation

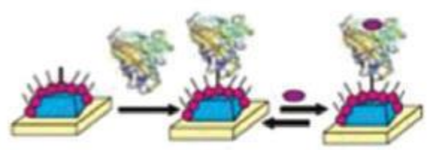
<u>How could one get a high sensitivity of the optical sensor for chemical compounds?</u>

1. Use of ultra-high light localization in a near-field of an optical resonator*

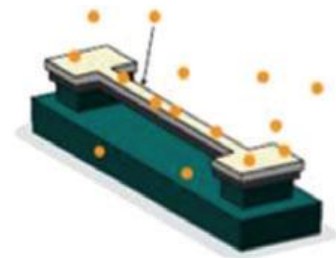
Ring resonator



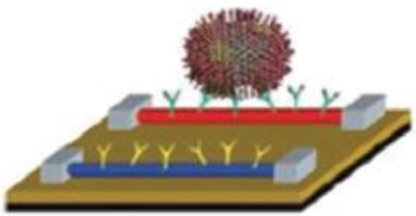
Plasmon resonance



Mechanical resonator



Nanowire



Advances: high light localization intensities provide a single-molecule detection.

Drawbacks: the probability of analyte molecule to reach a localization area is too small.

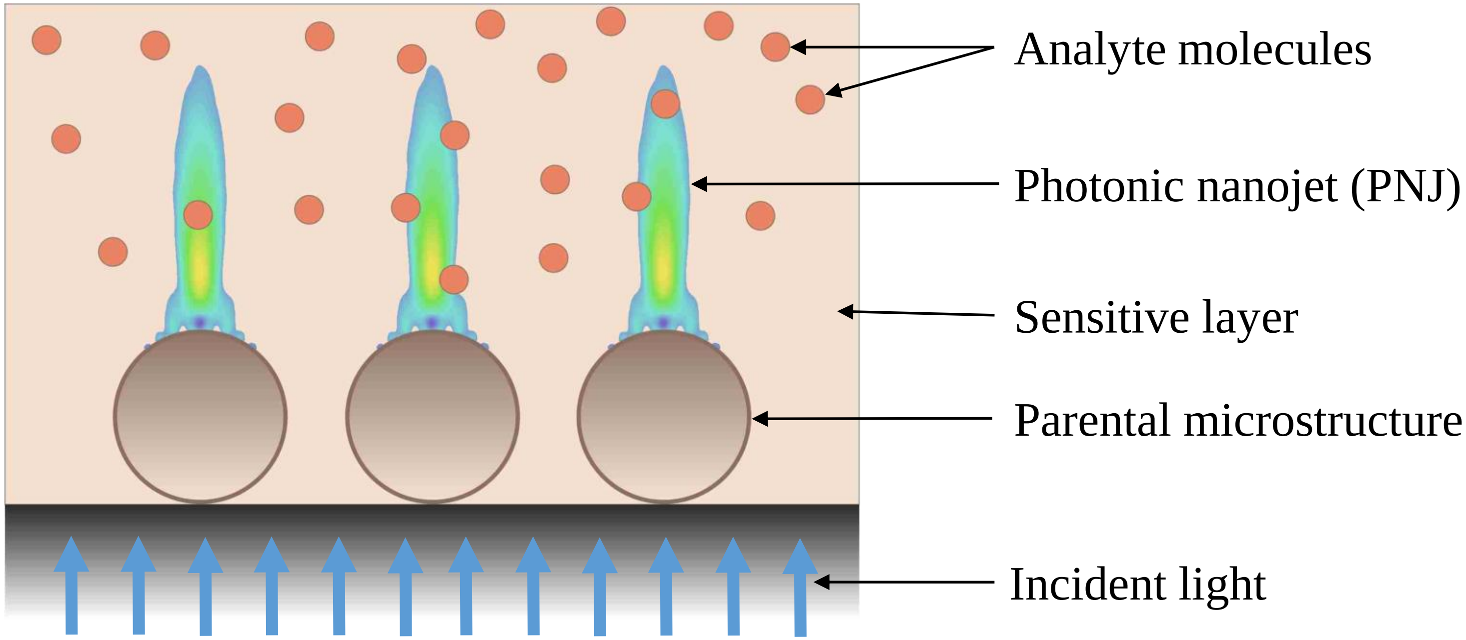
Solution: to use a photonic nanojet phenomena for extended light localization in a sensitive layer of the optical sensor.

*F. Vollmer, L. Yang, *Nanophotonics* **1** (2012) 267–291

Motivation

How could one get a high sensitivity of the optical sensor for chemical compounds?

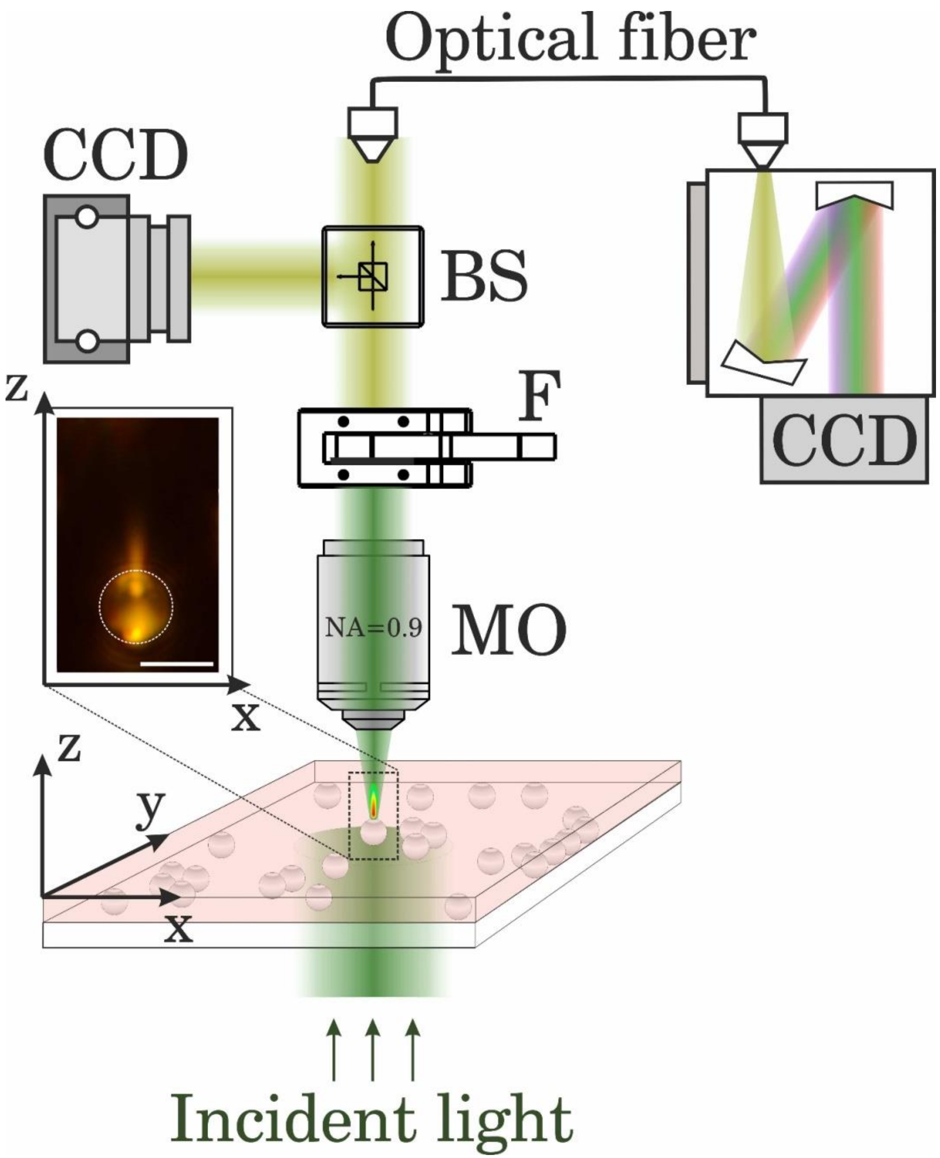
2. Extended light localization using photonic nanojets



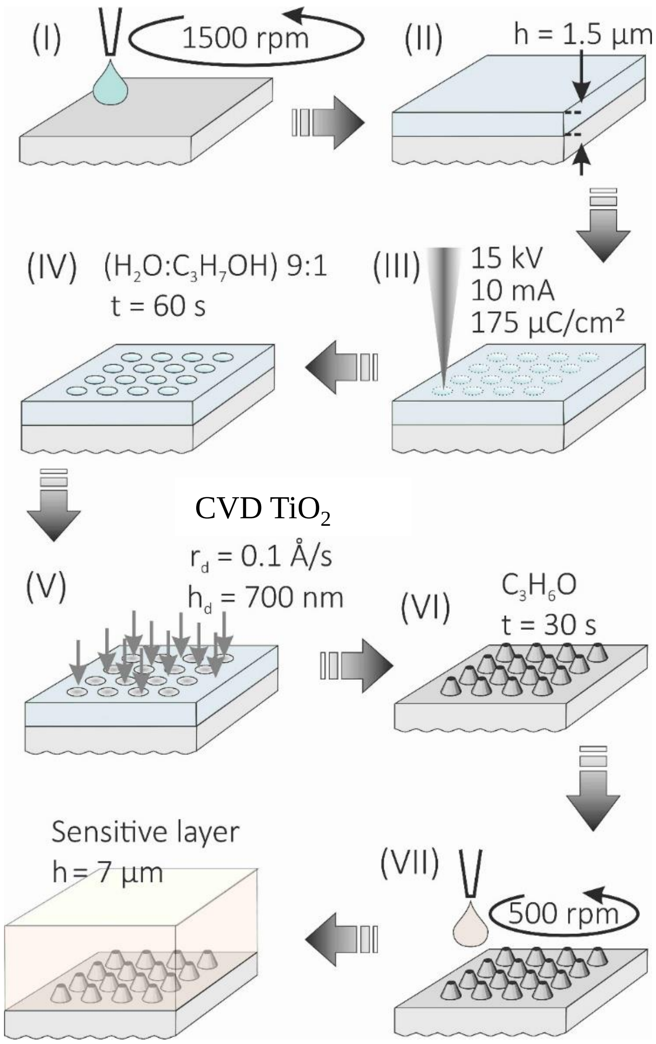
Advances: Extended light localization area increases probability of analyte detection.
Tracking of analyte concentration.
Possibility of sensing arrays formation.

Challenges: Development of fabrication technique of a parental microstructure array.
Optimization of microstructure parameters to achieve the highest performance.

Experimental setup



Sample preparation



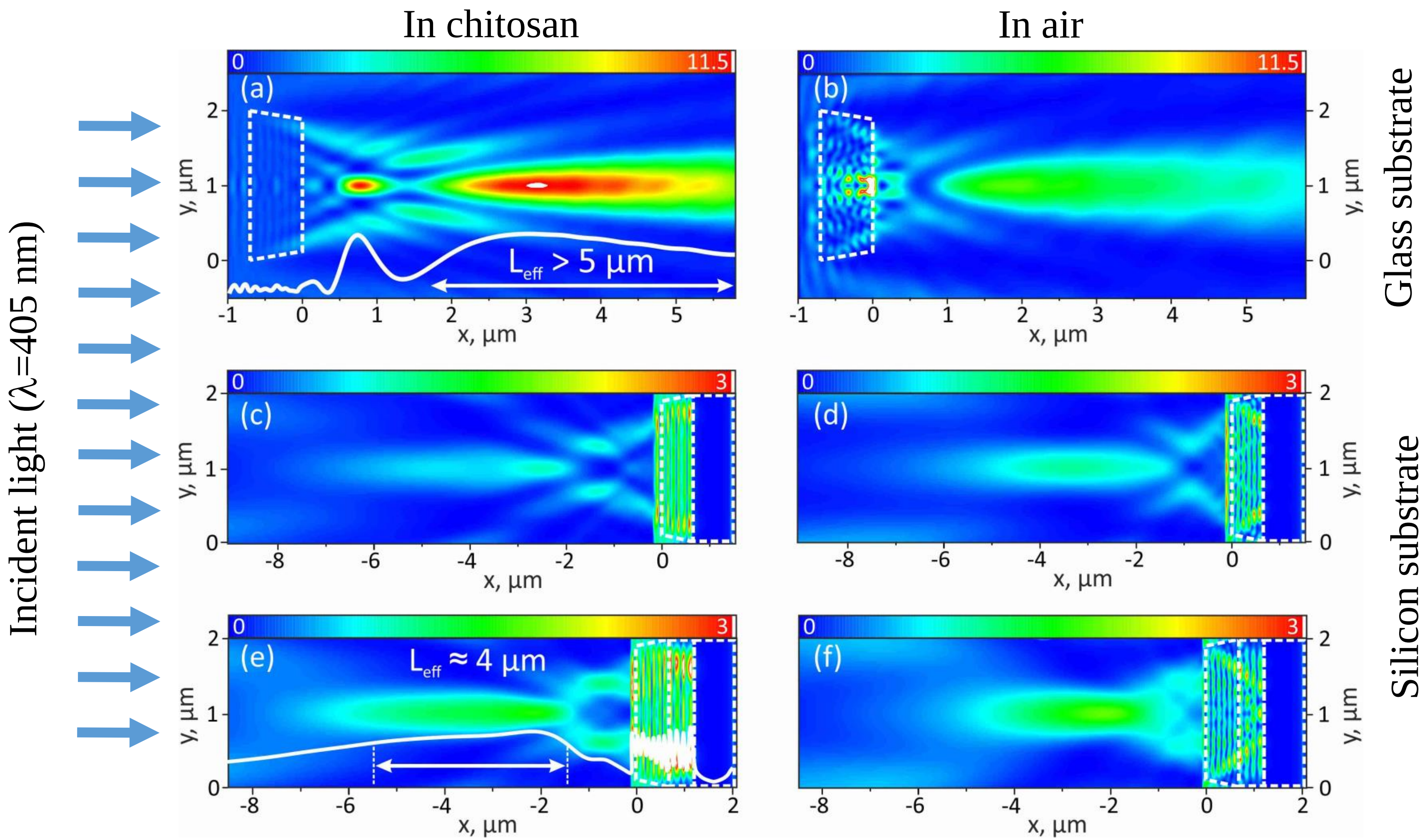
Sensitive layer: chitosan polymer doped by rhodamine 6G derivate*

Analyte: Au^{3+} ions

*A.Yu. Mironenko et al. *Tetrahedron* **75** (2019) 1492–1496

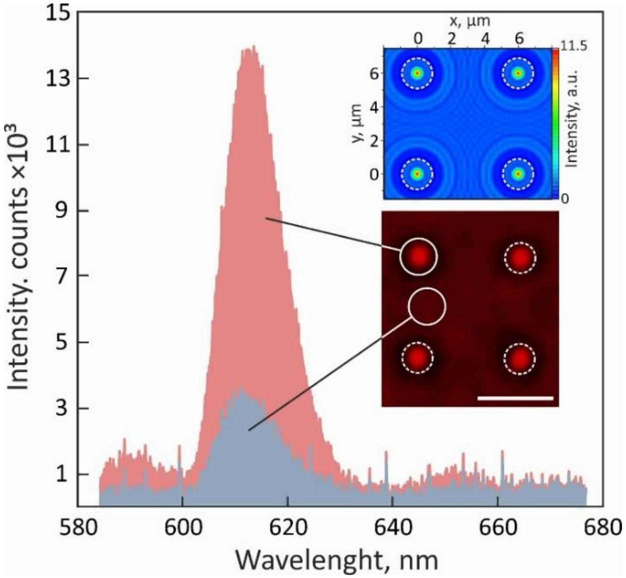
Numerical simulations

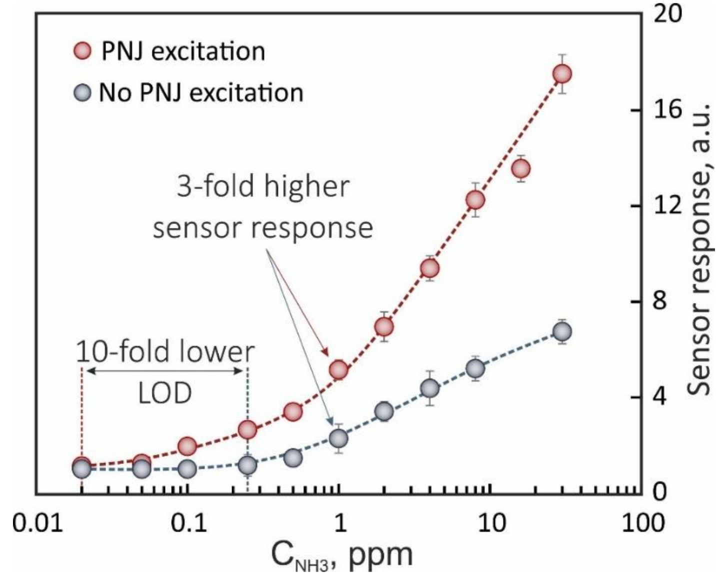
<u>The developed structures can generate PNJ both in reflection and transmission modes</u>



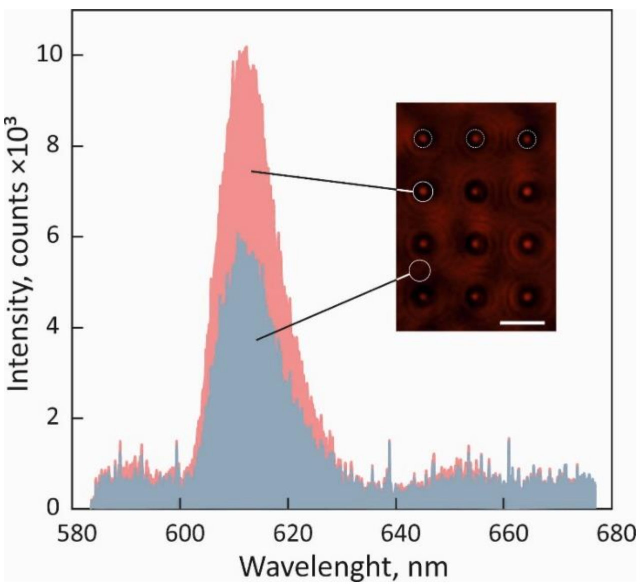
Once the microstructure is placed at a certain distance from the substrate it is possible to obtain **<u>PNJ in reflection mode without standing wave modulation</u>!**

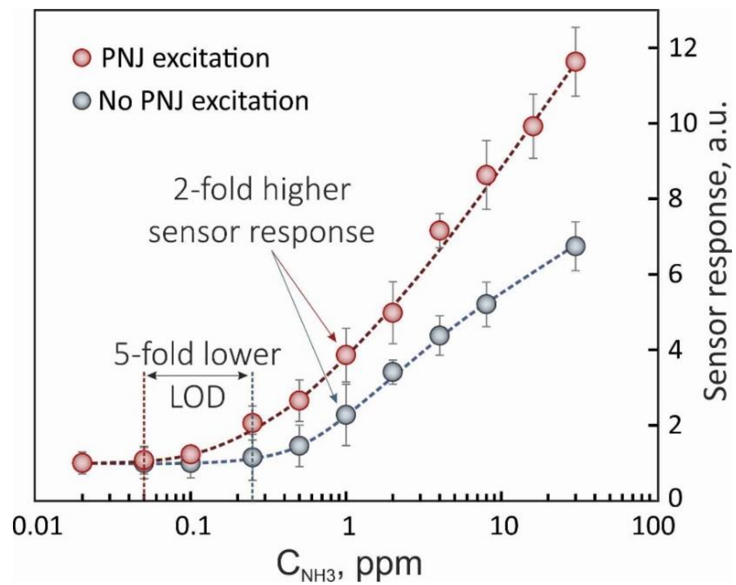
Sensor response





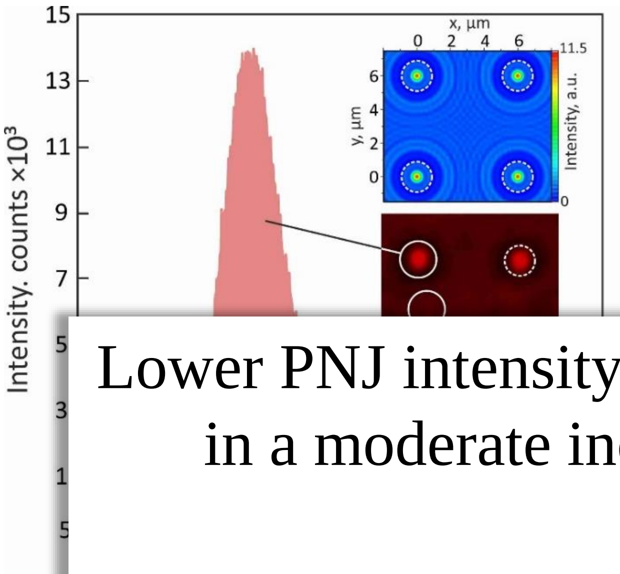
Transmission mode

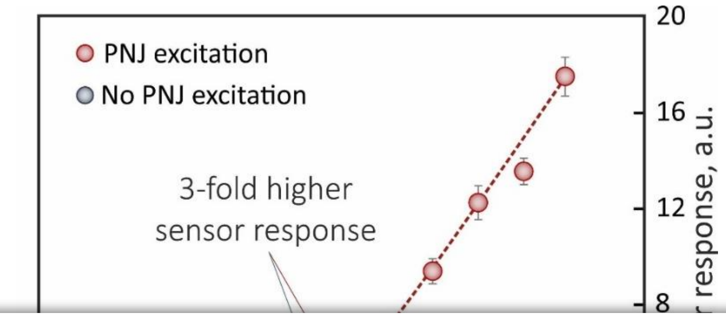




Reflection mode

Sensor response





Transmission mode

Lower PNJ intensity in transmission mode results in a moderate increase in sensor response

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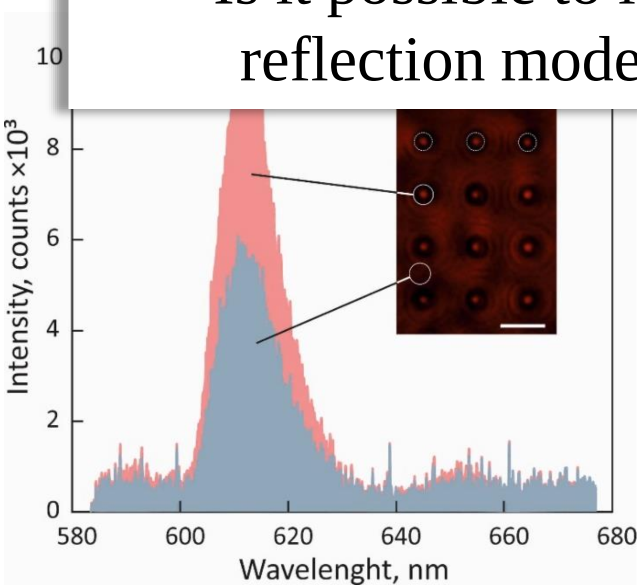
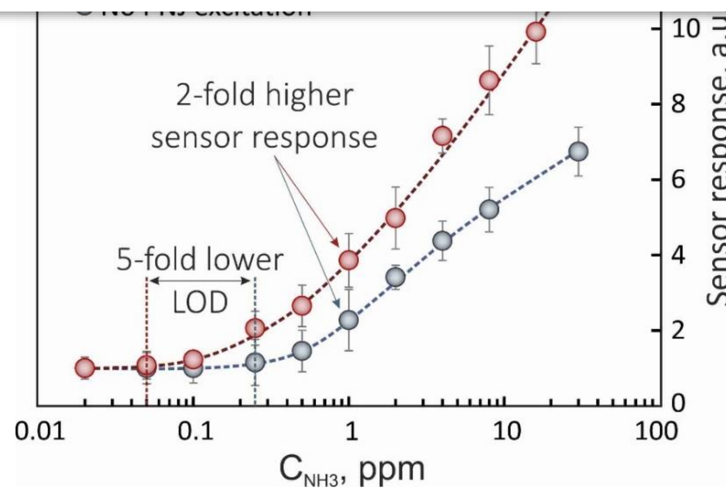
Is it possible to increase PNJ intensity in reflection mode, preserving its length?

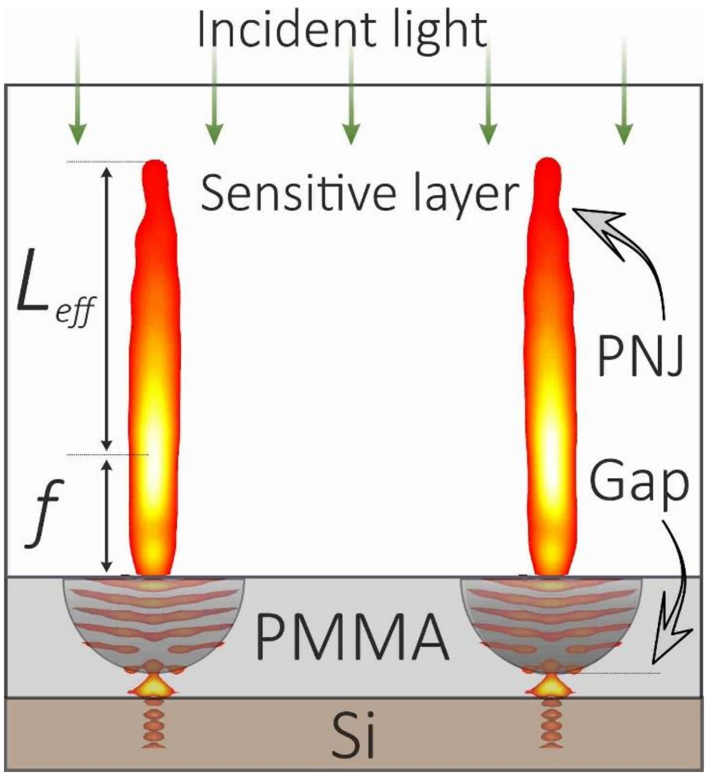




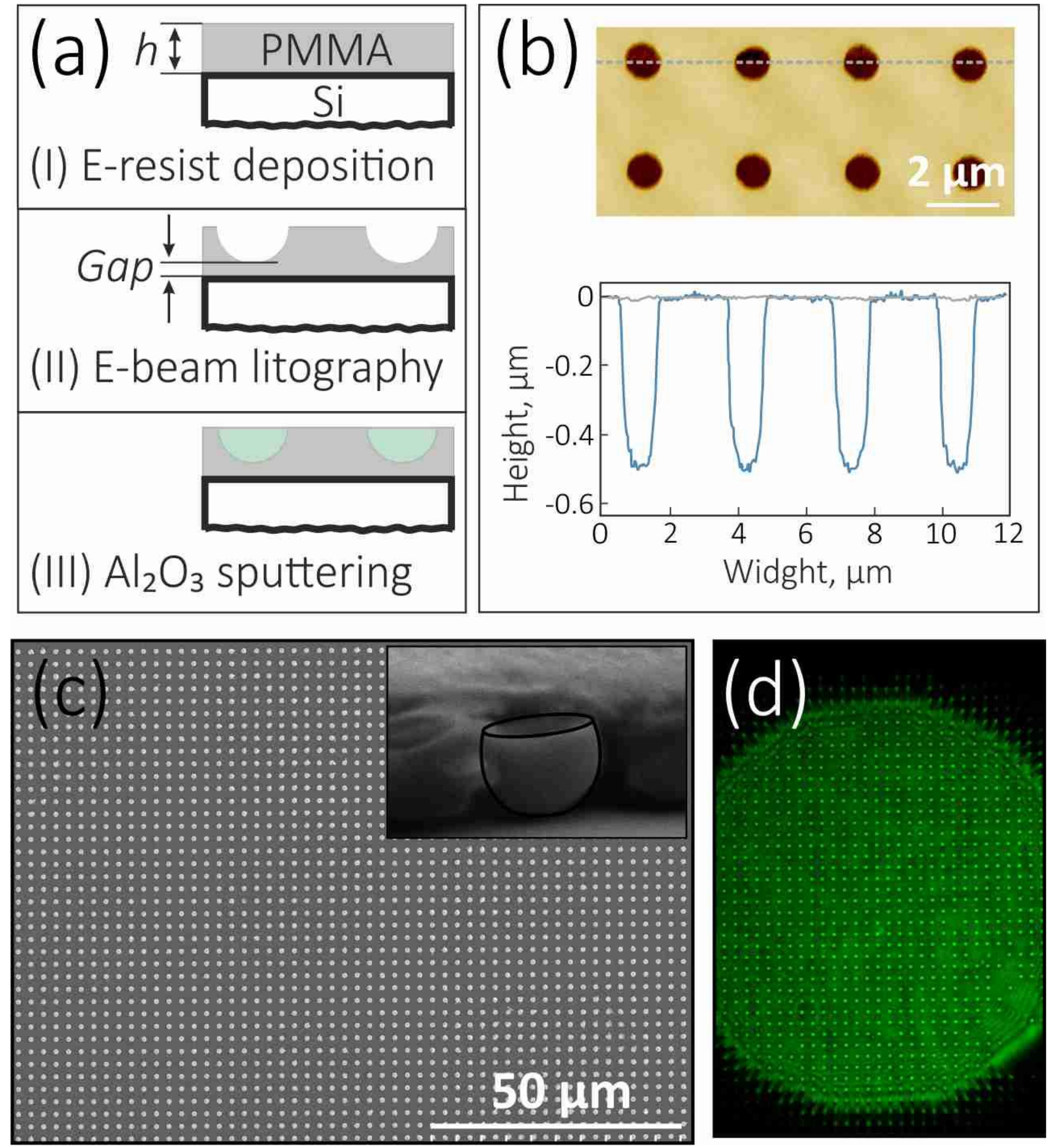
Reflection mode

Hemisphere-based optical system

Concept



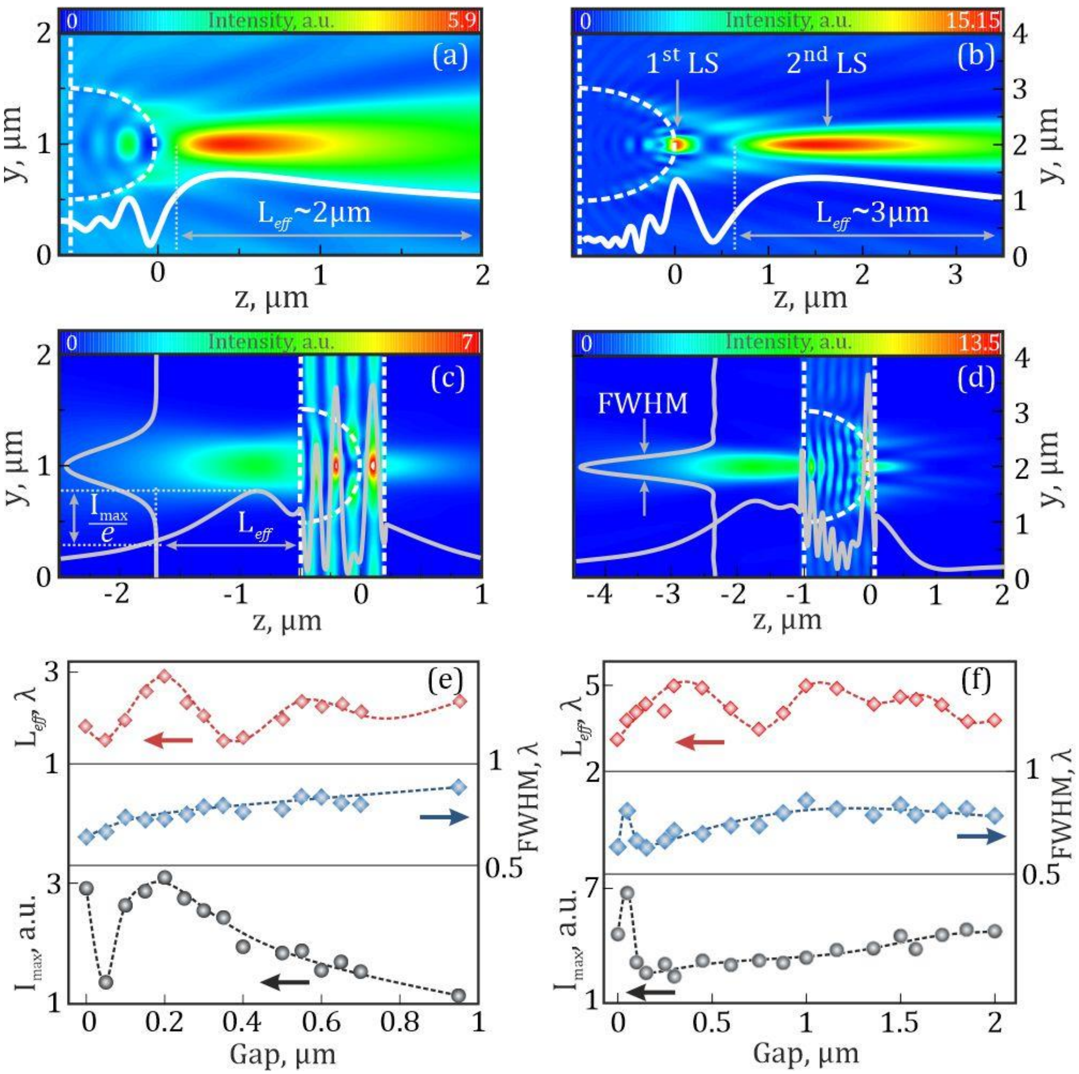
Fabrication process



(a) Scheme of fabrication process
(b) AFM-images of templates
(c) SEM-image of fabricated array
(d) Optical-image of fabricated array

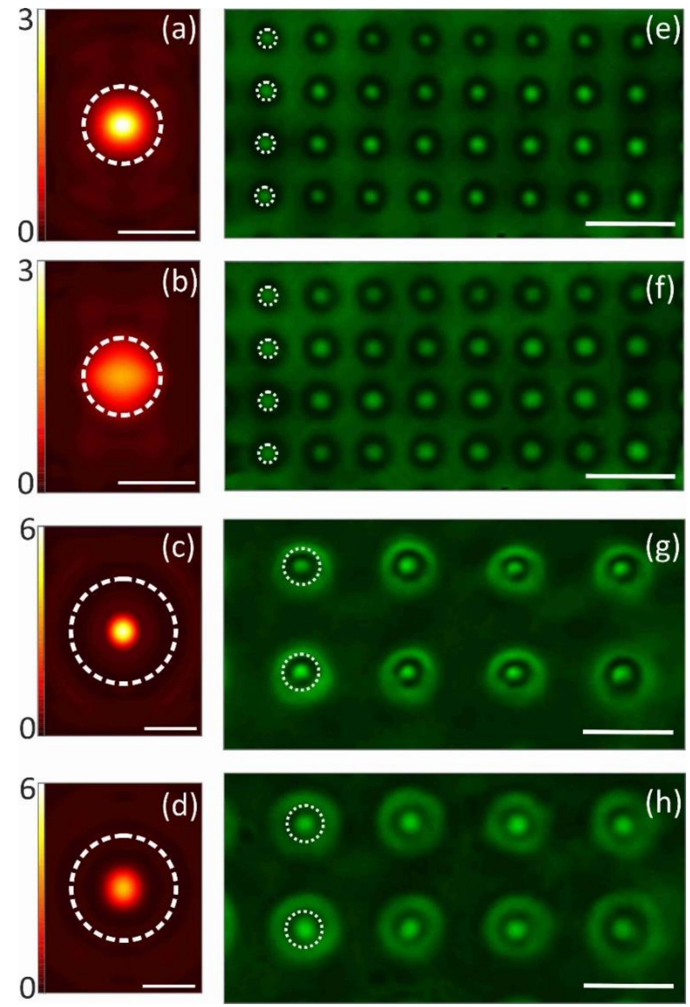
Hemisphere-based optical system

Numerical simulations



PNJ with the **highest intensity** appears at **certain gap** between the hemisphere and the substrate!

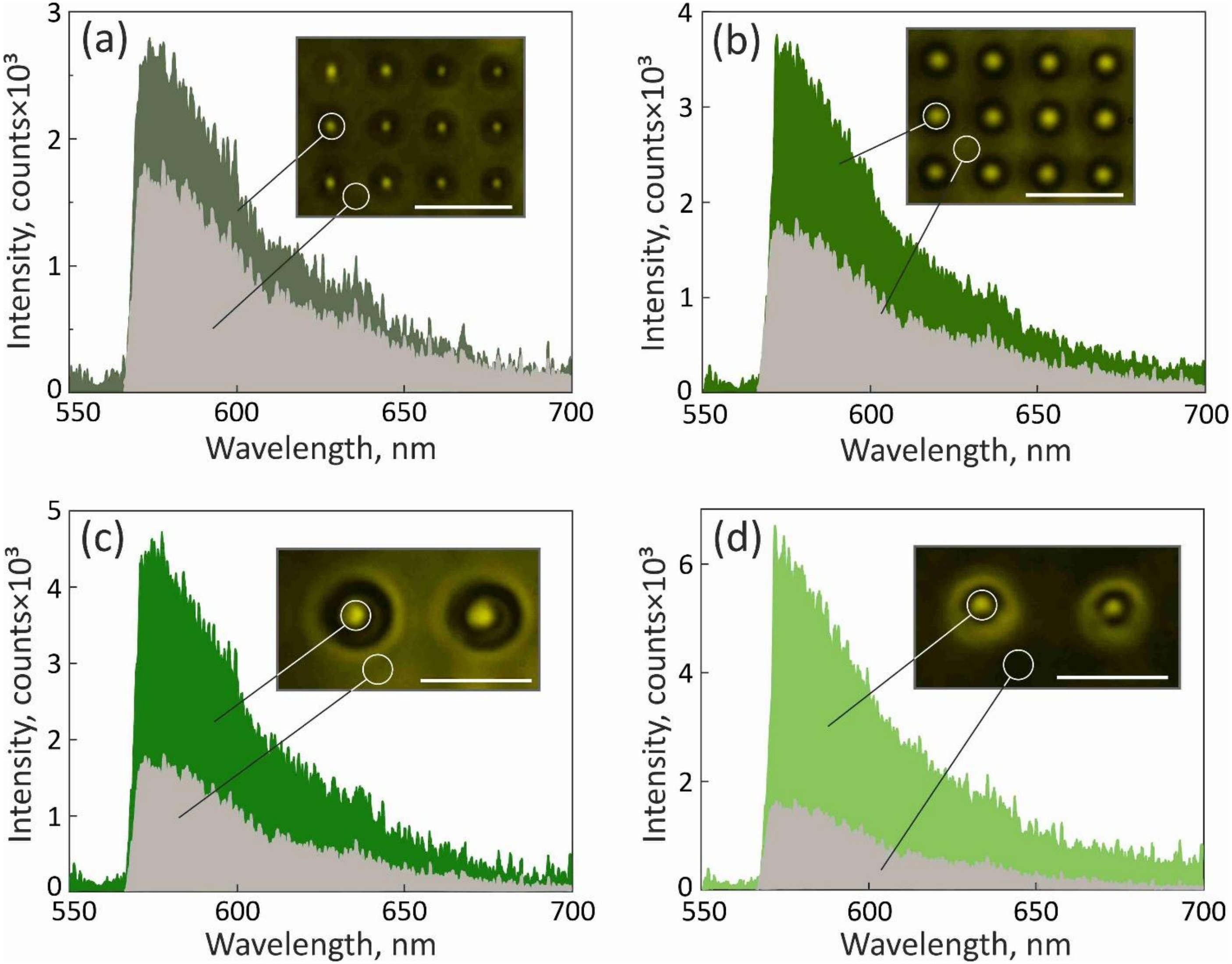
Experimental images



(a, e) 1μm hemisphere, gap 0.2 μm
(b, f) 1μm hemisphere, gap 0 μm
(c, g) 2μm hemisphere, gap 0.05 μm
(d, h) 2μm hemisphere, gap 0 μm

Hemisphere-based optical system

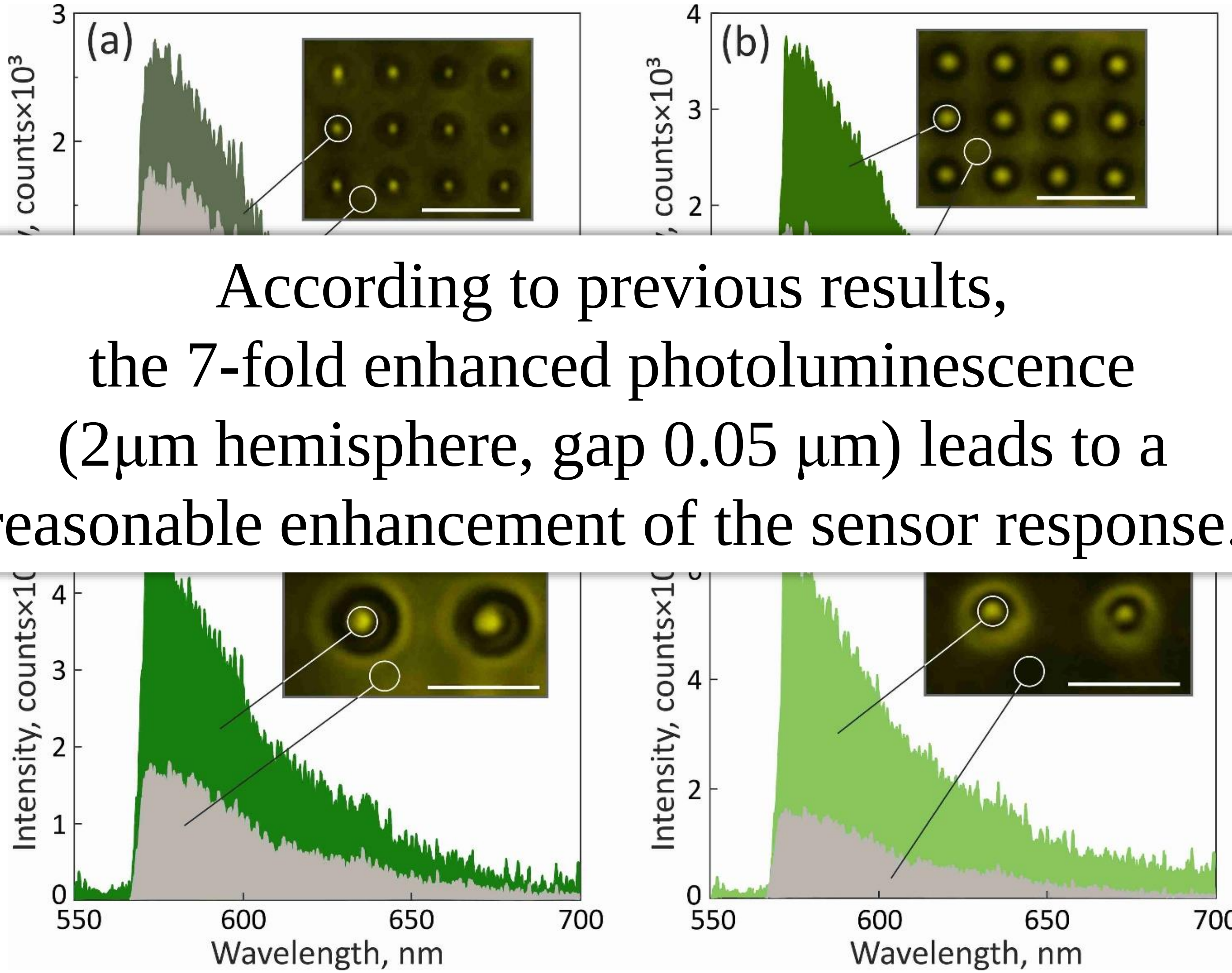
Photoluminescence enhancement



(a) 1μm hemisphere, gap 0 μm; (b) 1μm hemisphere, gap 0.2 μm;
(c) 2μm hemisphere, gap 0 μm; (d) 2μm hemisphere, gap 0.05 μm

Hemisphere-based optical system

Photoluminescence enhancement



According to previous results,
the 7-fold enhanced photoluminescence
(2μm hemisphere, gap 0.05 μm) leads to a
reasonable enhancement of the sensor response.

(a) 1μm hemisphere, gap 0 μm; (b) 1μm hemisphere, gap 0.2 μm;
(c) 2μm hemisphere, gap 0 μm; (d) 2μm hemisphere, gap 0.05 μm

Conclusion

1. Different types of PNJ generating microstructures were studied in the terms of photoluminescence and sensor performance enhancement.
2. The technique for fabrication of the ordered close-packed arrays of parental microstructures had been developed.
3. The limit of detection of the sensitive layer excited by PNJ depends on its length, while the photoluminescence and sensor response depend on the PNJ intensity.
4. The new type of PNJ in reflection mode without modulation by the standing wave was observed.

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