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Total number of authors:
11

Publication date:
2024

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Schröder, F., Xiong, M., Christiansen, R. E., Yu, Y., Casses, L., Semenova, E., Yvind, K., Wubs, M., Sigmund, O., Mørk, J., & Leitherer-Stenger, N. C. (2024). *Near-field characterization of deep sub-wavelength confinement in InP cavities*. Poster session presented at National Optics Congress 2024, Odense, Denmark.

Near-field characterization of deep sub-wavelength confinement in InP cavities

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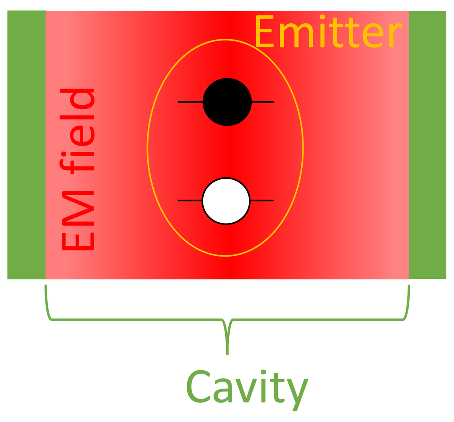
Abstract

We have achieved electromagnetic field confinement in an InP nanocavity with a mode volume $< (\lambda/2n)^3$. The experimental demonstration of sub-wavelength confinement is carried out by scattering-type scanning near-field optical microscopy with a pseudo-heterodyne detection scheme. Demodulation at higher harmonic orders of the tip tapping frequency enables retrieval of the scattered electric field with a nanoscale spatial resolution.

Motivation

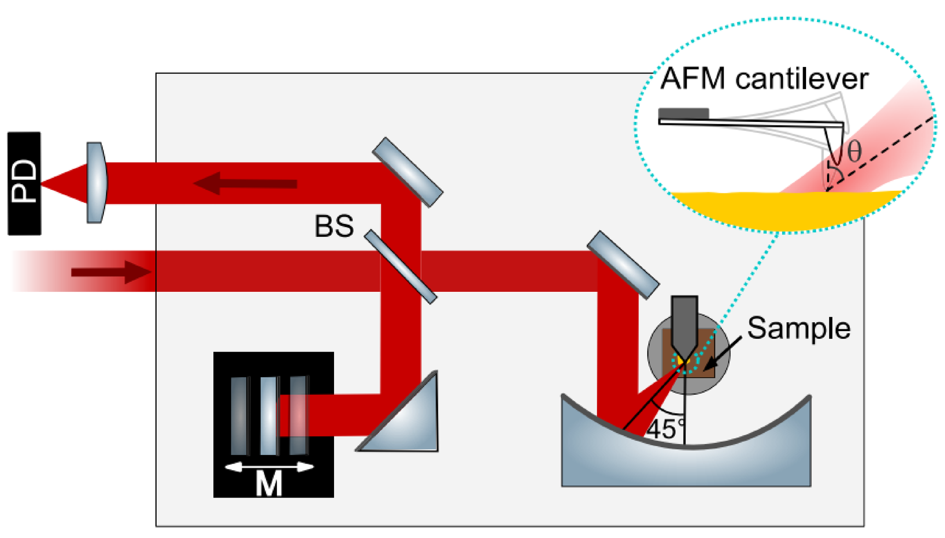


$$F_P = \frac{\tau_{3D}}{\tau_{\text{Emitter}}} \propto \frac{Q}{V}$$

Decreasing V in dielectric structures increases the Purcell factor. Sub-wavelength light confinement has recently been demonstrated in a Si-bowtie cavity [1]. For integration with active materials, a direct bandgap semiconductor like InP is favorable.

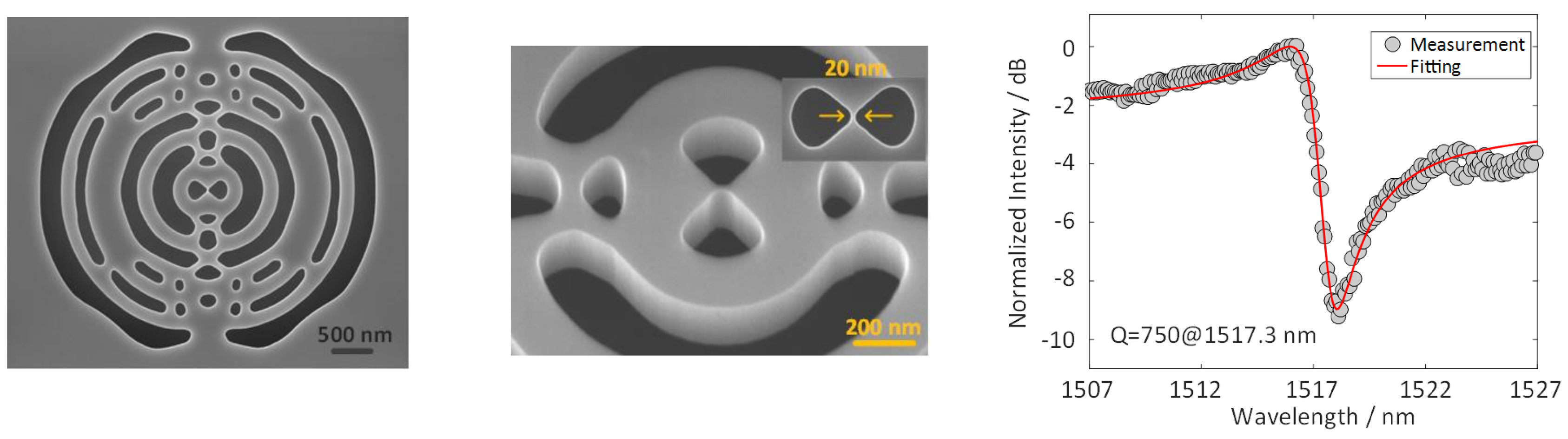
Setup

Scattering-type scanning near-field optical microscopy (sSNOM) [2]



In a sSNOM, a laser beam from a tunable CW laser is focussed on an oscillating AFM tip, yielding spatial field localization at the tip apex. Demodulation of the scattered light from the tip at higher harmonic orders of the tip tapping frequency and pseudo-heterodyne detection enables retrieval of the near-field information with a spatial resolution on the nanoscale.

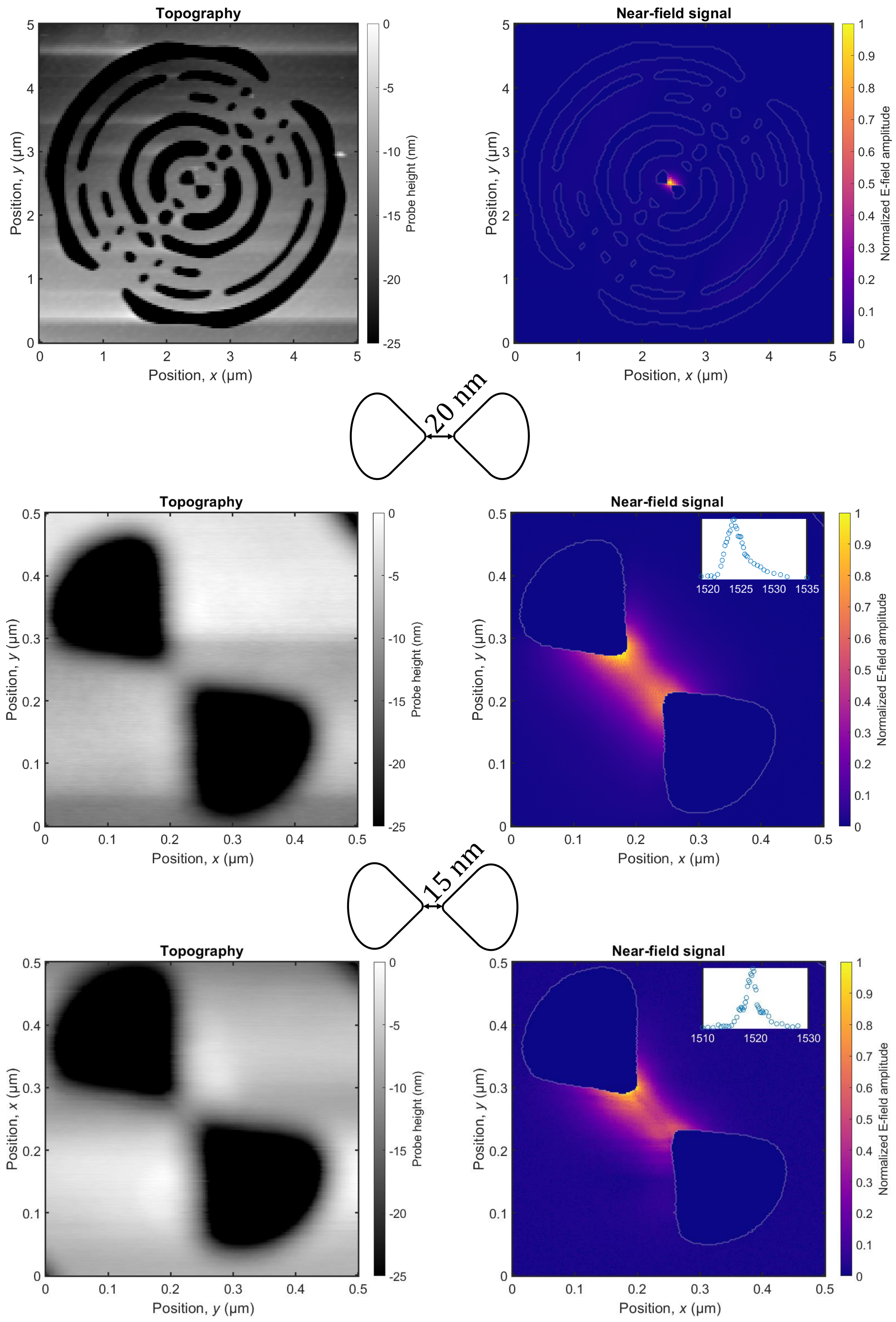
Fabrication and far-field characterization



Designing the extreme dielectric confinement (EDC) cavity exploits topology optimization [3], where the figure-of-merit Q/V is optimized. The structure is fabricated in InP with electron-beam lithography and inductively coupled plasma etching. Far-field measurements yield $Q{\sim}750$ at a resonance wavelength of $\lambda_c = 1517.3\ \text{nm}$ for a bowtie spacing of $20\ \text{nm}$ and $Q{\sim}600$ at $\lambda_c = 1507.8\ \text{nm}$ for a bowtie spacing of $15\ \text{nm}$.

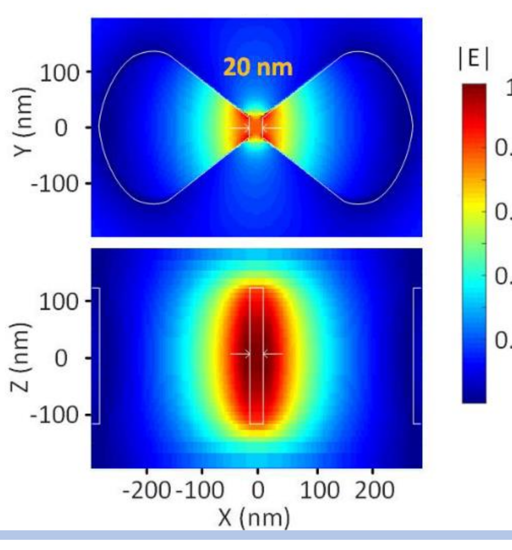
Experimental Demonstration

The electric field of the cavity is measured with the sSNOM:



→ Experimental demonstration of field confinement in the center of the bowtie cavity.

Simulations



FDTD-simulations yield a Q-factor of $\sim$1000 and a mode volume of $0.26\ (\lambda/2n)^3$ for a bowtie spacing of $20\ \text{nm}$, which is significantly below the so-called diffraction limit. Moreover, when reducing the bowtie spacing to $15\ \text{nm}$, simulations reveal $Q{\sim}800$ and $V{\sim}0.19\ (\lambda/2n)^3$.

References

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Publication:
M. Xiong, R. E. Christiansen, F. Schröder et al., *Optical Materials Express*, 14(2), 397 (2024)

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This work was supported by the Danish National Research Foundation through grant number DNRF147