PhD THESIS DEFENSE: A Topological Nanophotonics platform based on hyperbolic phonon-polaritons

LORENZO ORSINI

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12:00
Elements Room

Topological Nanophotonics is an emerging interdisciplinary field that offers a groundbreaking approach to control and manipulate light at the nanoscale. It combines principles from Topology, Photonics, and Nanotechnology to investigate the captivating behavior of light when confined to structures on the nanometer scale. A main goal of the community is to achieve topological edge states deeply confined below the diffraction limit. Despite promising theoretical and experimental progress, achieving these edge states in a Nanophotonic system remained elusive until now.

This thesis is devoted to achieving these Topological edge states in a Nanophotonic system by combining several methods. First, we used natural hyperbolic materials to take advantage of their high-quality sub-diffraction-limit electromagnetic modes, known as hyperbolic phonon polaritons. Additionally, we employed an indirect patterning technique to fabricate nanophotonic devices, solving fabrication-induced issues and allowing for the precise control over the nanostructures. Finally, we characterized these Nanophotonic systems using scattering-type scanning near-field optical microscopy. Achieving deep subwavelength topological edge states required several foundational achievements:

Quantitative Polaritonic Near-Field Analysis:

Scattering-type scanning near-field optical microscopy is a powerful imaging technique for studying materials beyond the diffraction limit. However, interpreting near-field measurements poses challenges in mapping the response of polaritonic structures to meaningful physical properties. To address this, we developed a theory using the transfer matrix method to simulate the near-field response of 1D polaritonic structures. This efficient and accurate analytical theory maps the near-field response to well-defined physical properties, enhancing the understanding of near-field images and complex polaritonic phenomena.

Advancing the Hyperbolic Platform:

The physics underlying our hyperbolic platform was largely unexplored, leading to a significant gap in understanding the fundamental properties and control methods of indirect patterned hyperbolic materials. Our studies provided new insights into the behavior of hyperbolic phonon polaritons in indirect patterned systems. We achieved three key results: first, we gained new insights into the fundamental behavior of hyperbolic phonon polaritons providing a deeper understanding of their interactions within indirect patterned systems; second, we investigated indirect patterned hyperbolic nanocavities achieving record-breaking quality factors, approximately 80, while maintaining the mode volume five orders of magnitude smaller than the free-space excitation wavelength; and third, discovering that the coupling mechanism between cavities is radiative, significantly impacting the design of lattices and photonic crystals using indirect patterning.

Achieving Deep Subwavelength Topological Edge States:

We experimentally demonstrated deep subwavelength topological edge states by implementing a one-dimensional lattice based on the Su-Schrieffer-Heeger model. The topological edge state was confined in a sub-diffraction volume of $0.021?m^3$, four orders o magnitude smaller than the free-space excitation wavelength volume used to probe th system, while maintaining a resonance quality factor above 100

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Thesis Director: Prof. Dr. Frank Koppens

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