Spatial and Spectral Mapping of Supercontinuum Level-Crossing

Nitzan Shani[1], Amit Kumar Shakya[1], Fan Cheng[1] , Vladimir Shuvayev[2], Lev Deych[3], and Tal Carmon[1,*]

[1] School of Electrical Engineering, Tel Aviv University, Tel Aviv 6997801, Israel. [2] Physics Department, Queens College of CUNY, Flushing, Queens, New York 11367, USA. [3] The Graduate Center of CUNY, 365 5th Ave., New York, New York 10016, USA.

Author e-mail address: total@tauex.tau.ac.il

We experimentally demonstrate a new type of level coalescence where resonances accompany each other along broad spectral bands. Beyond extending the known types of level crossing (simple, avoided, and exceptional), our coalescing levels might transform current supercontinuum-generation technology to be continuous in frequency and also in time [cw].

1. Introduction

From Landau levels[1] to exceptional points[2], spectral singularities were setting the limits of spectral measurements. Here, we experimentally demonstrate supercontinuum levels, hosted by a cylindrical resonator, accompanying each other over a broad frequency span. Potential applications include top-flat filters and supercontinuum sources. Cylindrical resonators exhibited weak localization that benefitted nm scale diameter measurements and were mapped using tapered fiber[3], but their resonances were never photographed before. Our microcavity is a semi-infinite cylindrical resonator[3] that fully confines light along its circumferential and radial directions, associated with integer azimuthal and radial quantum numbers, M and R. Yet, the weak confinement of light along the axial direction of this long cylinder results in a non-discrete azimuthal quantum number, k_z. For example, a resonance with integers azimuthal and radial numbers (e.g., M=700 and R=2) can have an axial k_z quantum number continuously changing from 0.1 to 4 [1/μm] (Fig. 1). One can excite several of these modes (e.g., having a different M number) while using a single wavelength laser, generating an interference pattern that we fluorescently photograph (Fig. 1b). Tuning the laser via resonances, while monitoring transmission, provides the spectral response of the resonator (Fig. 1a). Simultaneously, we spatially map these modes using a fluorescent material converting the coherent resonance light into longer-wavelength, incoherent, and non-directional light; that is filtered, collected, and photographed using a camera (Fig. 1b). Altogether, the simultaneous spatial and spectral mode mapping of our semi-infinite cylinder reveals two or more modes supercontinually accompanying each other while generating a variety of interference patterns (Fig. 1).

2. Experimental results

We submerge a 125 μm diameter silica cylinder in a fluorescent liquid while its circumferential resonances are excited using a tapered fiber[4]. The photographs in Figure 1b exhibit, for the first time, the spatial shape of an interference pattern generated by two accompanying modes that populate the cylindrical cavity. These photographs are part of a movie showing that the shape of this mode (Fig 1b) is continuously spatially evolving as we scan the input-light wavelength. The azimuthal number of the photographed fringes (e.g. 7) corresponds to the difference between the azimuthal numbers of the interfering modes (e.g., $\Delta m=752-745=7$). This number does not change during the scan, as expected from their stationary azimuthal order difference, Δm (Fig. 1c-d) and in accordance with what we see in our movie. As for the axial number of fringes, the axial fringe density varies during the scan, in accordance with what is expected from their changing axial moment, k_z, (Fig. 1d) and as seen in our movies. A similar supercontinuum level crossing is seen also with three resonances, indicated by the co-existence of 7 and 10 circumferential fringes (Fig. 2) in experimental results and theoretical calculation (Fig 2)

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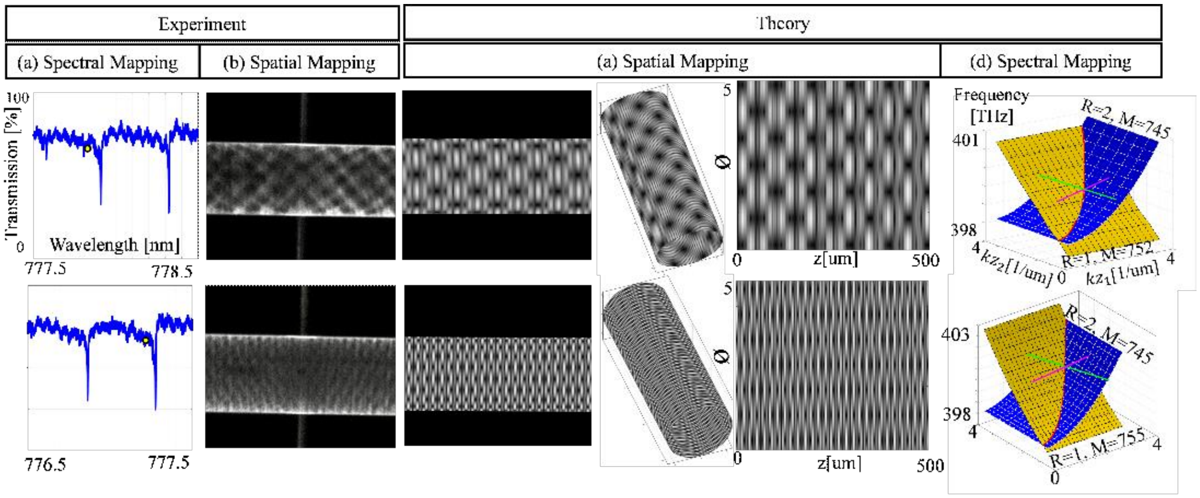

Figure 1. Spectro-spatial mapping of accompanying levels of a cylinder. (a-b) Experimental results where the yellow point on the spectral transmission (a) corresponds to the photograph (b) where the interference between resonances with different azimuthal and radial numbers is seen. (c) The corresponding numerical calculation of the best fitting modes and their calculated (d) omega-k_z diagram where the red line represents the spectral band where these two modes can be continuously excited.

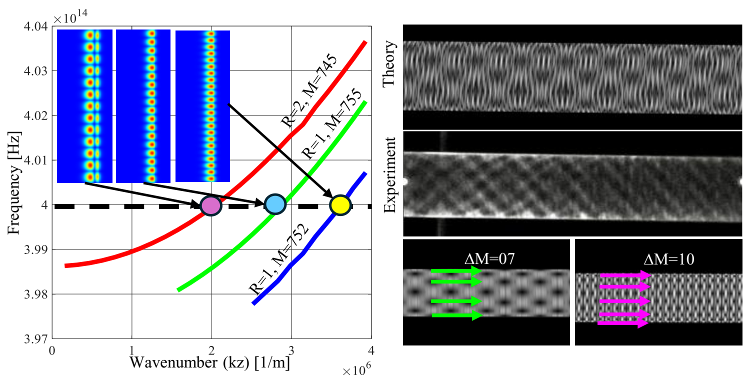

Figure 2. Triply accompanying modes (top) frequency-momentum calculation showing three cylinder's modes, with different axial momentum k_z that one can excite to resonate at the same frequency (dashed line) to interfere azimuthally and axially (bottom).

3. Conclusion

We spectrally and spatially mapping reveals, for the first time, a variety of interference patterns that are continuously tuned with wavelength. The continuous axial quantum numbers (k_z) of these modes, the ability to co-host several of them, continuously in frequency, might impact supercontinuum sources by transforming them to be continuous also in time [CW]. Furthermore, such micro-cavities might benefit automatic phase-matching related to the fact that the required energy conservation is satisfied for a continuous momentum and for several modes.

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