Diabolical points in coupled active cavities with quantum emitters

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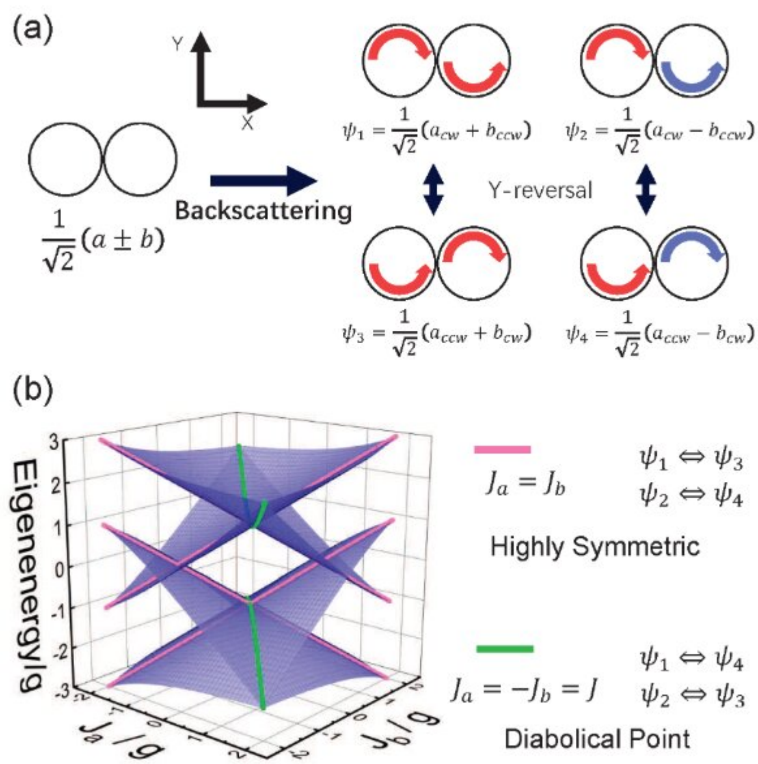

Figure 1 | (a) The schematics of two pairs of reversal states with the backscattering. Red arrows refer to + while blue arrows refer to −. (b) Four eigenvalues with $J_{a,b}$ of different values. Pink lines refer to results with $J_a = J_b$. Green lines refer to results with $J_a =- J_b$.

Credit: Jingnan Yang, Chenjiang Qian, Xin Xie, Kai Peng, Shiyao Wu, Feilong Song, Sibai Sun, Jianchen Dang, by Yang Yu, Shushu Shi, Jiongji He, Matthew J. Steer, Iain G. Thayne, Bei-Bei Li, Fang Bo, Yun-Feng Xiao, Zhanchun Zuo, Kuijuan Jin, Changzhi Gu, and Xiulai Xu

Diabolical points (DPs) introduce ways to study topological phase and peculiar energy dispersion. Scientists in China and partners from the United Kingdom demonstrated DPs in strongly coupled active microdisks. A new macroscopical control of backscattering based on the competition between defects and quantum emitters was used to achieve DPs. This work paves the way to integrate DPs and more exotic phenomena into quantum information processes with quantum emitters, and will inspire further research with DPs.

DPs originate from parameter-dependent degeneracies of a system's energy levels. Due to the topological Berry phase, DPs play a fundamental role in physical and chemical dynamics, such as peculiar photonics in 2-D materials or condensed matter systems which provide topological quantum processing. Meanwhile, active emitters in photonic structures are essential for the coherent electron-photon interface in the quantum photonic network. Therefore, realizing DPs in active photonic structures can greatly benefit the implementing of quantum information processing and scaling up in the quantum network. However, multiple quantum emitters in active cavities are usually randomly positioned, thus resulting in symmetric and uncontrollable backscattering which forbids a degeneracy with only trivial eigenstates. As a result, the coherent interface between electrons and photons at DPs is hard to achieve.

In a paper newly published in *Light Science & Application*, scientists from Institute of Physics, Chinese Academy of Sciences and co-workers demonstrate DPs in two strongly coupled microdisks with embedded quantum dots (QDs). Due to that the individual control of each QD is impossible, a macroscopical control of backscattering was proposed based on the competition between two types of scatterers (QDs and defects), which solves the problem of low controllability. Through optimization, a balanced competition was successfully achieved with backscattering coupling strength from negative to positive in single microdisks, clearly demonstrated by the experimental statistics. Furthermore, compared to single microdisks with two-dimensional Hamiltonians, two strongly coupled microdisks have supermodes with four-dimensional Hamiltonians. The spectra are affected by not only the absolute backscattering coupling strengths but also their signs. Thus, coupled cavities are a good platform to study the fundamental physics of backscattering and make DP possible. Hermitian degeneracies at DPs were observed when the backscattering coupling strengths in two microdisks have the same absolute value but in the opposite signs.

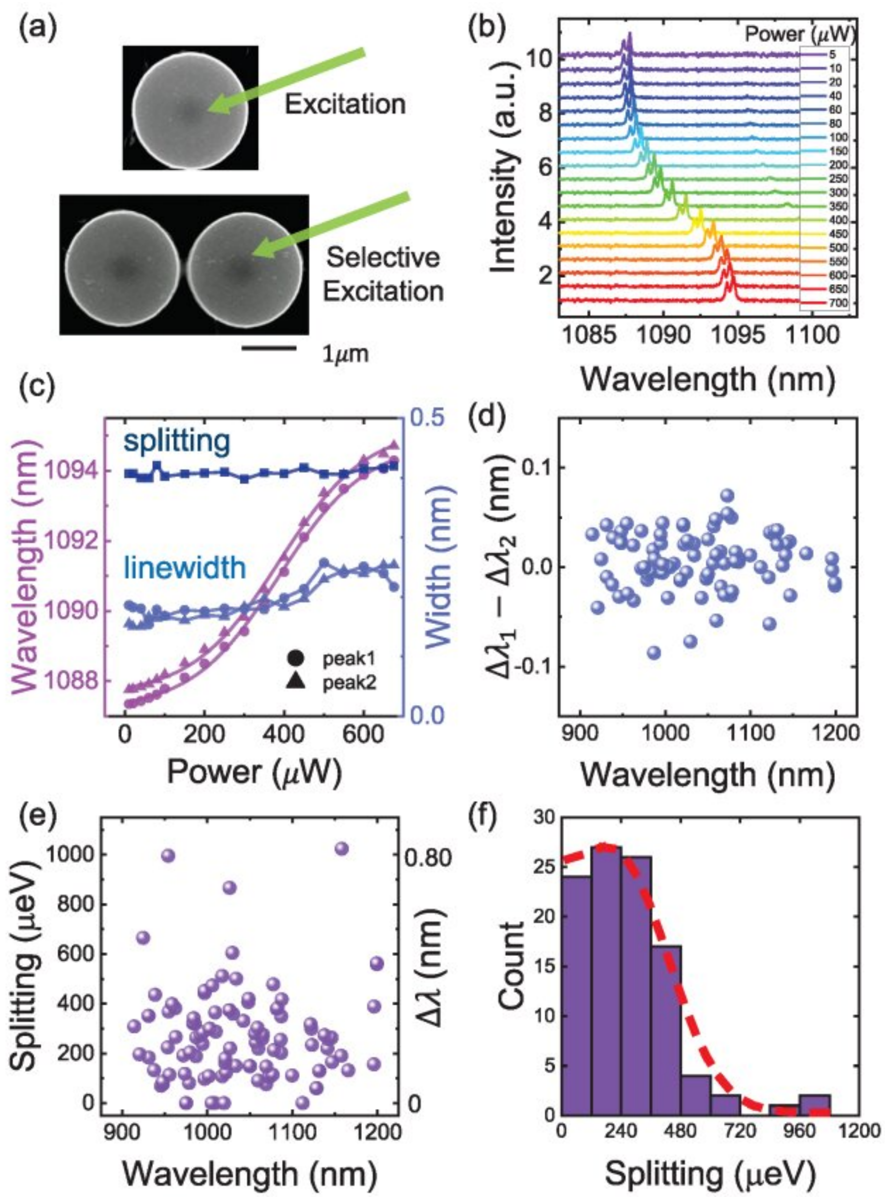

FIG. 3. (a) SEM images of single and double microdisks. The excitation laser is labeled by the green arrow. (b) The red shift of cavity modes with increasing excitation power. (c) The wavelengths, linewidths and splitting between two peaks extracted from Lorentz multi-peak fitting. (d) Statistics of linewidth differences between split modes. The resolution of the spectrometer is 0.1 nm. (e) Statistics of the splitting. The splitting of 1000 μeV corresponds to 0.80 nm at the wavelength of 1000 nm. (f) Distribution of the splitting and half Gaussian fitting.

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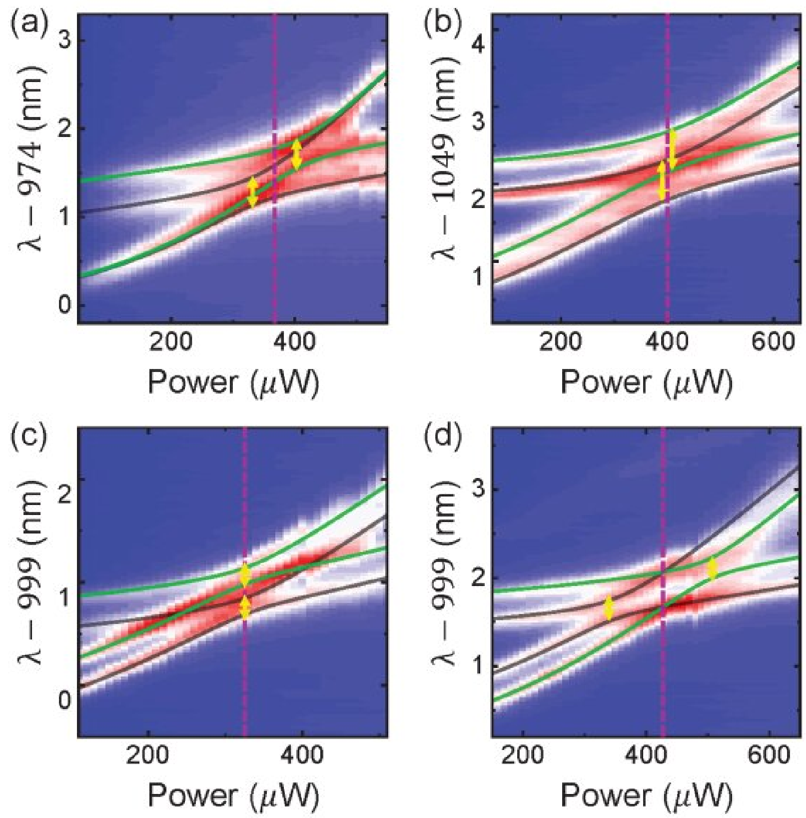

FIG. 4. Excitation-power-dependent PL maps of coupled cavities and the fitted results with different $J_{a,b}$. The resonance $\omega_a = \omega_b$ is marked by purple dash lines. (a) $J_a = 0$ and $J_b \neq 0$. (b)-(c) $J_a J_b > 0$. (c) $J_a = J_b$. (d) $J_a J_b < 0$ and $J_a = -J_b$. DPs occur at resonance.

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At DP of two coupled cavities, the system has eigenspaces in which the phases of two microdisks have a nonlinear correlation, indicating a controllable phase shift between them. Therefore, the two coupled cavities are a potential in directional laser and quantum phase control. Moreover, when the interaction between emitters and cavities is improved in the future, this system can be predicted with an important role in studying quantum DP behaviors and integrating photons at DPs into quantum networks.

"The randomly positioned quantum dots and defects are very hard to control and can result in symmetric backscattering. We introduced the macroscopical control based on the competition between different types of scatterers and achieved backscattering coupling strength with both negative or positive values."

"We experimentally demonstrated one pair of DPs in the spectra with two strongly coupled microdisks, which are different from the ordinary DP without backscattering or in a single perfect microcavity. DPs here can produce nonlinear correlation with a phase shift between two microdisks, with potential application in optical quantum information processing, topological optics and fundamental physics at DPs using photonic structures," the scientists said.

More information: Jingnan Yang et al, Diabolical points in coupled active cavities with quantum emitters, *Light: Science & Applications* (2020). DOI: 10.1038/s41377-020-0244-9

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https://phys.org/news/2020-01-diabolical-coupled-cavities-quantum-emitters.html