Spatial and temporal control of cavities

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Semiconductor microcavities have proven to be essential for light confinement in space and storage in time and that facilitate manipulating light matter interactions [1]. The control of the cavity refractive index spatially and temporally will allow for complete control over the light stored in a cavity; in real space, wavevector space, frequency space, and in time domain. For instance, the control of the refractive index of a cavity at ultrafast time scales enables to convert the frequency of light stored in a cavity [2]. The spatial control will allow for controlling the coupling of the cavity to the environment and enable to shape the mode profile.

The generation of light with a controllable frequency is a long standing challenge. Literature has it that the physics of frequency conversion in a cavity differs from traditional non-linear optics, regarding the rate of phase change and output spectrum [2,3]. Here, we unify these disparate views. We have reversibly switched the resonance of a GaAs-AlAs microcavity in the near-infrared within 300 fs by the electronic Kerr effect [3]. We reveal by pump-probe spectroscopy a remarkable red or blue shift of the light confined inside the cavity, depending on the timing of pump and probe pulses. The color-converted light is generated in a broad frequency continuum that differs markedly from the instantaneous cavity resonance. From observations on cavities with a range of quality factors, we identify the role of the local density of optical states (LDOS) available to the newly generated light frequencies. We distinguish effects of the LDOS due to the cavity resonance, and the surrounding vacuum that tunnels into the cavity. This concept from cavity quantum electrodynamics allows us to present a unified physics framework for frequency-conversion in both traditional homogeneous and in nanophotonic media [4]. As application of the new physics, we demonstrate color-converted pulse trains at a THz repetition rate and illuminate our control in time and frequency space.

Arrays of coupled high-Q nanocavities, collectively provide a superior system than a single cavity and can be used to observe light localization [5, 6]. A challenge remains; namely to fabricate an array of cavities at the same resonance frequency to observe localization. Due to technical limitations, fabrication of many high-Q cavities at the same resonance frequency is not simply achievable. Here, we control the resonance frequency of each cavity individually by locally changing the refractive index in an InGaP photonic crystal cavity array. We use wavefront shaping to shape the pump beam and we address individual cavities [7]. As a result, we spatially control the refractive index and manage to manipulate the coupling of the cavities. We show that we can counteract the unintentional shift of the cavity resonance frequency and we can bring multiple cavities to a collective resonance spatially controlling the refractive index.

References

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