Photonic Metamaterial Continuous Time Crystal

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Abstract: We report that a classical metamaterial nanostructure, a two-dimensional array of plasmonic metamolecules supported on flexible nanowires, can be driven to a state possessing all the key features of a continuous time crystal: coherent illumination resonant with the metamolecules' plasmonic mode triggers a spontaneous phase transition to a superradiant-like state of transmissivity oscillations resulting from many-body interactions among the metamolecules, and which is characterized by long-range order in space and time.

A time crystal, as originally proposed by Wilczek[1], is a quantum many-body system whose lowest-energy state is one in which the particles are in oscillatory motion. Although it has been shown that such a system, breaking continuous time-translation symmetry by exhibiting oscillatory dynamics, is prohibited by nature, a number of systems which show discrete time-translation symmetry-breaking imposed by an external modulated parametric drive have been recently realized on various platforms, including trapped atomic ions, spin impurities, ultracold atoms, condensates of magnons and quantum computers. Recently, a quantum time crystal that breaks time-translation symmetry *continuously* has been observed in an atomic Bose-Einstein condensate inside an optical cavity. Continuous time crystals are also potentially of great interest in photonics as they can support a variety of new wave propagation phenomena.

We show that a 2D lattice of plasmonic metamolecules supported on doubly-clamped nanowires cut from a semiconductor membrane (Fig. 1a) spontaneously transitions, at room temperature, to a continuous time crystal analogue state characterized by persistent transmissivity oscillations when illuminated by coherent light that stimulates interaction among the metamolecules. Above a threshold of incident optical power, the spectrally dispersed thermal fluctuations of the individual nanowires become spatially coherent synchronous oscillations

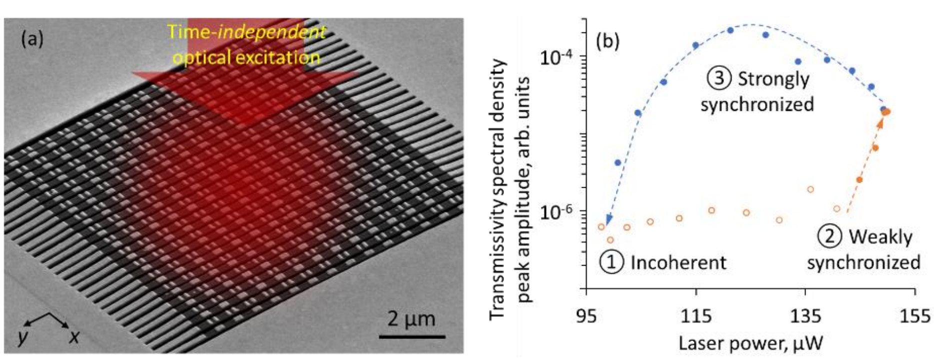

Figure 1: (a) Metamaterial continuous time crystal constructed as an array of nanowires decorated with plasmonic metamolecules. (b) Light-induced interactions among metamolecules lead to synchronized motion of the nanowires via a 1st-order phase transition, resulting in a manifold increase of transmissivity modulation.

over the illuminated ensemble (Fig. 1b).

The phenomenon points to a new mechanism for the synchronization of noise-driven, linear oscillators based upon *non-reciprocal* coupling. The simplicity and control achievable in the nano-opto-mechanical metamaterial platform, offer a new path towards applications in all-optical modulation, frequency conversion and timing, and for the study of dynamic classical many-body states in the strongly correlated regime.

References

1. F. Wilczek, "Quantum Time Crystals," Phys. Rev. Lett. Vol. 109, 160401 (2012).