TERAHERTZ WAVEPLATES

Paper option

A simple stack of ordinary white paper can be used as a high-quality polarization waveplate for the terahertz spectral region, according to researchers in Germany and the USA (*Opt. Express* **19,** 24884–24889; 2011).

Benedikt Scherger and co-workers from Philipps Univerisität Marburg, University of Arizona and the University of Colorado cut standard office paper (120 μm thick and with a weight of 80 g m^{-2}) into strips and stacked them with alternating air gaps formed by spacers. They then used a clamp or rubber bands to hold the resulting stack of 150–200 paper–air pairs in position.

Characterization of the stack's properties in the terahertz region revealed that it was strongly birefringent, with refractive indices of 1.295 and 1.149 for p- and s-polarized light, respectively, at a frequency of 0.244 THz. This allowed the stack to rotate the polarization of incident terahertz light and thus function as a waveplate.


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By placing the paper stack between traditional wire grid polarizers, the researchers were able to make transfer function measurements of the paper waveplate's performance. Data show that transmission contrast ratios as high as 40 dB are possible, suggesting that the waveplate can rotate a linear polarization state as well as output a pure polarization state, with negligible depolarizing.

The behaviour of the stack was not perfect: it exhibited polarization-dependent loss, with s- and p-polarizations experiencing different levels of attention. For frequencies of around 0.25 THz, however, the overall transmission losses due to absorption were less than 5 dB.

"These waveplates have the advantage of being extremely cheap and easy to fabricate," comment the authors of the study. "They show excellent performance at their design frequency."

The researchers are now thinking of constructing paper achromatic waveplates for operation over wider bandwidths based on the use of multiple plates of varying thickness.

OLIVER GRAYDON

QUANTUM OPTICS

Correlations on a chip

Researchers have developed a semiconductor structure capable of supporting quantum correlations between photons and strong single-photon nonlinearities, thus paving the way for the development of chip-based devices for quantum secure communications and quantum information processing.

XinAn Xu and Chee Wei Wong

Cavity quantum electrodynamics describes the behaviour of a quantum emitter inside an optical cavity, and is one of the few realizable experimental systems in which the coherent interaction between the emitter and the cavity mode can exceed dissipative and dephasing processes. Recent advances in this field include the observation of vacuum Rabi splitting[1–3], interference[4], upconversion[5] and the metasurface enhancement[6] of single photons, as well as cavity–exciton photon blockade and tunnelling[7] on a semiconductor chip. In addition, by varying the local density of optical states to control spontaneous emission, researchers have demonstrated highly efficient quantum dot single-photon sources with sub-Poissonian statistics[8].

Now, writing in *Nature Photonics*, Reinhard *et al.*[9] report strong photon–photon quantum correlations on the first and second Jaynes–Cummings manifolds for a single quantum dot coupled to a photonic crystal nanocavity, even in the presence of quantum dot blinking. The behaviour of a two-level quantum emitter–cavity system is described by the Jaynes–Cummings standard model[10,11], in which spontaneous emission can be controlled through coherent atom–vacuum field interactions. The quantum emitter–cavity system is described by the Rabi interaction rate g, the quantum emitter decoherence or decay rate γ, and the cavity photon decay rate κ. In the weak coupling regime, the emitter or the cavity photon decay rate is greater than the Rabi interaction rate. There is an irreversible energy exchange between the emitter and the cavity photon, with a Purcell-modified spontaneous emission rate that is based on the local density of states.

In the strong coupling regime, the Rabi interaction rate exceeds the cavity or quantum emitter decay rate, with reversible spontaneous emission and multiple re-absorption/re-emission oscillations between the emitter and the cavity mode. The resulting strongly coupled open system exhibits the solid-state analogue of vacuum Rabi splitting with normal-mode splitting in the spectral domain, and is significantly perturbed by the detection event[10], which collapses the wavefunction and causes the second-order correlation function at zero time delay, $g^{(2)}(0)$, to tend to zero. This is understood as the stochastic renormalization of the cavity emission rate after the first photon emission, which has strong photon antibunching character.

The exciton–photon polariton energy ladder displays distinct anharmonicity. When probed on the second rung of the Jaynes–Cummings ladder, the strongly coupled polariton system can exhibit photon bunching, thereby providing optical nonlinearities at the few-photon level that would be useful for chip-scale quantum information processing.

Using techniques described in previous work[12], Reinhard *et al.* ensured strong coherent exciton–photon interactions by carefully aligning and coupling a single quantum dot to a photonic crystal defect cavity with several missing holes (Fig. 1). Careful fabrication of the photonic crystal structure provided a cavity quality factor of ~25,000, with exciton–photon Rabi frequencies of up to 30 GHz and g/κ values as high as 2.7.

The researchers used cross-polarization resonant spectroscopy to investigate the resulting quantum-dot photonic crystal cavity system. Hanbury-Brown and Twiss measurements revealed regions within the energy manifolds that exhibited interesting correlation effects. In particular, the researchers observed photon antibunching (where the first cavity photon blocks subsequent events) for resonant excitation of the lowest-energy polariton state. They also observed photon bunching (an increased likelihood of two photons entering the cavity simultaneously) when the laser field was in two-photon resonance with polariton eigenstates of the second Jaynes–Cumming manifold.

Theoretical predictions based on Monte Carlo wavefunction computations, taking into account the non-perfect experimental features, match the photon–photon statistical measurements of bunching and antibunching.

The quantum dot samples in this work exhibited appreciable blinking (random temporal switching between bright and dark states of photoluminescence)[13], which is a common phenomenon in quantum dots or other emitters. Because the long-lived defect states involve a charged or dark state in addition to the simplistic two-level emitter model, the exciton resonance is shifted away from the cavity resonance and therefore strong exciton–photon polariton states are not observed. Reinhard *et al.* combined repumping with a time-multiplexed non-resonant scheme to reshuffle the internal state of the quantum dot. Through this pump–repump technique, the quantum dot is brought back to the neutral ground state when excited just below the material wetting layer resonance. This allows the strong coupling Rabi splitting to be observed again, in the time-averaged spectra. Because this technique does not completely remove blinking, the resulting spectrum exhibits a three-peak structure. Blinking suppresses bunching at zero laser-cavity detuning and actually makes the bunching at the second manifold more pronounced.

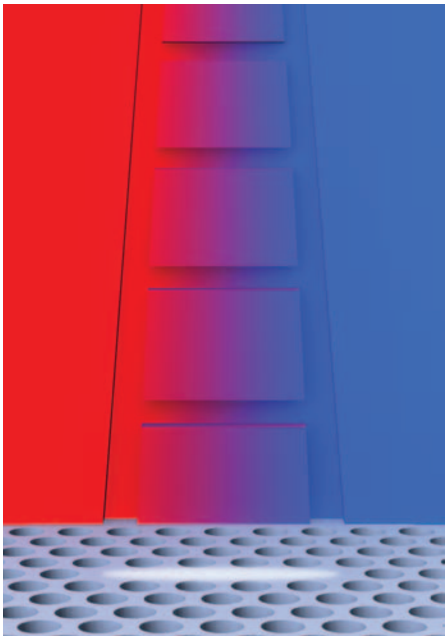

Figure 1 | Reinhard *et al.* have observed strong photon–photon correlations by carefully aligning and coupling a single quantum dot to a photonic crystal defect cavity.

The observation of correlated photon states on a semiconductor chip platform is a cornerstone in the development of chip-scale quantum information processing. The results are a key step towards the realization of quantum registers[14] and systems combining arrayed quantum emitters and cavity polaritons[15,16] in an integrated quantum photonic platform. ❐

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TERAHERTZ PHOTONICS

Coherent terahertz synthesizer

Photonic manipulation of the spatial distribution of charge in relativistic electron bunches provides a promising way to generate intense coherent terahertz radiation.

Masahiro Katoh and Serge Bielawski

An appealing goal for photonics researchers is the development of methods for synthesizing light waves; that is, a means of creating customized waveforms with control over their wavelength, amplitude and number of cycles. Schemes capable of achieving this for terahertz radiation include optical rectification and transient current control in semiconductors[1–3].

Recent advances in particle accelerator technology now enable scientists to generate coherent terahertz emission from electron bunches (as opposed to synchrotron radiation, which is incoherent). Such coherent emission can be produced by applying a longitudinal terahertz modulation to an electron bunch before it is radiated during deflection by a magnetic field (coherent synchrotron radiation) or when colliding with a metallic target (coherent transition radiation).

The great interest in this topic stems partly from a spectacular scaling law of the emitted power for coherent schemes. For a given electron bunch size, the power emitted by coherent synchrotron radiation or coherent transition radiation scales with N^2 (ref. 5), where N is the number of electrons in the electron bunch. In contrast,