Phase controlled atom-field interaction: from superradiance to superabsorption

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A novel platform for phase-controlled atom-field interaction is described. A nanohole-array atomic beam aperture placed in front of a high-Q cavity allows us to localize two-level atoms traversing the cavity at the desired positions \([1]\). Combined with a transverse pump laser positioned between the nanohole array and the cavity mode, we can prepare the individual atoms after going through the nanoholes in a superposition state of the ground and excited states with a prescribed phase. With a centered-square-lattice nanohole array with the hole spacing equal to the transition wavelength \(\lambda\) of the two-level atom, we can prepare every atom in the same superposition state. With this configuration, we have observed the coherent single-atom superradiance, where \(N_c\) atoms traversing the cavity in the cavity-field decay time cooperatively emit photons into the cavity mode although the mean number \(N\) of atoms in the cavity is less than unity \([2]\). This interaction results in the cavity photon number growing proportional to \(N_c^2\) and exhibiting a thresholdless lasing even when the so-called beta factor, the ratio of the spontaneous emission into the cavity mode to the total spontaneous emission, is much less than unity. Moreover, we have succeeded in reversing the superradiance in time to realize superabsorption for the first time. In superabsorption, the rate of atomic absorption is proportional to \(N^2\) in contrast to the ordinary absorption proportional to \(N\). This feat is achieved by adjusting the phase of the atomic superposition state in such a way that the phase of a prospect superradiant field these atoms would emit becomes exactly opposite to that of the input field. We experimentally observed that the number of photons completely absorbed for a given time interval is proportional to \(N^2\), a definitive evidence for superabsorption \([3]\).