Reversible orbital angular momentum photon-phonon conversion

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Experimental details. In our experiments, A frequency-doubled Q-switched Nd:YAG laser produces single-longitudinal and single-transversal Gaussian pulses with duration 10ns and linear polarization at 1Hz repetition rate. The OAM beams in this work are converted by SPPs (RPC Photonics, VPP-1c and Vpp-1064) and q-plates from Gaussian beam. Different energy detectors (Ophir PE-9, PD-10 and Newport 818E-10-25-S) are used, depending on laser energy level. The nonlinear media in SBS and Coupling Cells (30cm) are both CS₂, and a polarization decoupling method is adopted for avoiding probe-seed coupling in coupling cell. The plane Stoke-shift reference beam for producing interference pattern is produced by SBS (for frequency matching). All beams' powers are below the threshold of SBS to avoid self-SBS noise, where the energy of pump, seed and probe are set to 2mJ, 0.5mJ and 2mJ, respectively. Probe's path is a tunable delay path, and the waveform of reconverted Stokes signal is detected by a photoelectric detector connecting the oscilloscope. The pulse shapes shown in Fig-1(b) and Fig-3(a) are the results of an average 20 times.

q-plates of $q=0.75$ and $q=0.5$, $p=1$ are used to generate the beams of $\ell=1.5$ and $\ell=p=1$, as shown in Fig. S1, more details see ref. [36,37]

Fig. S1. The micrographs of q -plates used in experiments, $q=0.75$ (left) and $q=0.5$, $\ell=1$ (right).

Additional discussion. Here we additionally discuss the case of focused-SBS with an OAM pump based on results in this work. We should note that collimated vortex pump beams usually do not transfer OAM to phonon field, as collimated-SBS is an interaction between pump and noise phonons. Partial noise, component of satisfying phase matching, will be enhanced by collimated-SBS without OAM transfer unless the noise including vortices. Here, we concern the case of focused-SBS with OAM pump, which will transfer OAM to phonon field. Supplementary Figure S2 is experimental setup for focused-SBS of pump carrying OAM of $\ell=1$. At the first step of focused-SBS, the focused-pump constructs a coherent phonon field with vortices ($\ell=1$), and then two processes in SBS will perform: (a) BAPA process between the pump beam and the constructed acoustic field, according to Eq. (5), here the OAM conservation is $L_x |\ell_p\rangle = L_x (|\ell_k\rangle + |\ell_s\rangle)$, and the output Stokes state should be $|\ell_k\rangle = |\ell_p - \ell_s\rangle = |1-1\rangle = |0\rangle$. (b) SBA process between pump beam and Stokes signal generated in process (a), here the seed $|\ell_s\rangle$ is played by Stokes $|\ell_k\rangle$, and according to Eq. (2), the output Stokes state should be $|\ell_k\rangle = |\ell_s\rangle = |\ell_p - \ell_p\rangle = |1-1\rangle = |0\rangle$. Thus, the OAM carried by pump will be continuously transferred to phonons in ideal condition, or in other words, no optical phase conjugation occurring, and the experimental results shown in Fig. S2 (b1-b3) confirm this point. Notice that the results shown in Fig. S2 is the most common situation, we also occasionally observe some pattern with singularity meaning that phonon OAM state is not always $\ell=1$. This result is caused by many factors, a major concern point may be spin-orbital coupling in focused OAM beams, and a detailed analysis about this part will be further studied in the future.

Fig. S2. Schematic presentation and experimental results of focused-SBS. (a) Experimental setup for focused-SBS of pump carrying OAM. The input pump carrying an OAM of $\ell=1$ which is converted from a Gaussian beam by a SPP, and the output Stokes beam is reflected from PBS. (b1) Observed intensity profile of pump. (b2,b3) the intensity profile (b2) and interferogram (b3) of output Stokes.