In the process of two-photon emission (TPE), the transition between quantum levels occurs via virtual states, resulting in the simultaneous emission of two photons. These transitions are described by a second-order process in the time-dependent perturbation theory; hence, they are much weaker than the first-order one-photon transitions.

For this reason, observation of multi-photon spontaneous decay has so far been restricted to a few atomic transition cases, where the lowest-order process is forbidden. Semiconductors have high carrier densities, making even these relatively weak transitions measurable. Two-photon absorption in semiconductors has been substantially investigated. However, semiconductor TPE has been neither observed nor theoretically analyzed before.

We have proposed semiconductor TPE as a compact high-rate source of entangled photons operated at room-temperature.\(^1\) Entangled-photon states are essential in various applications of optical quantum information, including quantum computation, imaging\(^2\) and quantum cryptography. In specially designed semiconductor quantum wells (QWs), the TPE transitions must have zero angular momentum change, and photon pairs emitted collinearly will have opposite polarizations to be separated by a polarization beam-splitter. The energy conservation for this process does not specify the energy of each individual photon, and the emitted two-photon state is therefore energy-entangled with pair generation rates as high as tens of GHz.

Recently, we have also reported the experimental observation of TPE from semiconductors with a typical wide-spectrum with relatively high efficiencies—near 20 nW output power. In our experiments, semiconductor structures were electrically pumped below the one photon lasing threshold, which was increased to above 200 mA by anti-reflection coatings.\(^3\)

We have also shown nonlinear two-photon gain in semiconductors, which can provide the possibility for intrinsic mode-locked laser operation, allowing the generation of ultra-short optical pulses in compact practical semiconductor devices.\(^3,4\)\(^4\)

References

Cooling Silicon Raman Lasers with Coherent Anti-Stokes Raman Scattering

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A
n important issue when operating optically pumped lasers is the heat dissipation inside the active medium due to the quantum defect between the pump and the lasing wavelength. The resulting increase in temperature can have detrimental consequences on the performance of the laser. Most conventional heat disposal techniques based on water or air cooling are not ideal in terms of downscaling the laser volume or mitigating thermally induced refractive index changes and stresses in the medium. Therefore, intrinsic heat-mitigation mechanisms, which minimize the heat generation already inside the medium, are highly desirable.

Over the past decade, much progress has been made in the field of so-called “anti-Stokes fluorescence cooling.” Hereby, solid-state materials are cooled by the conversion of incoming pump photons into higher energy anti-Stokes fluorescence photons. In 1999, Bowman introduced the concept of the “radiation-balanced laser,” where anti-Stokes fluorescence cooling was used for suppressing the heat generation in the laser’s active medium.

However, efficient anti-Stokes fluorescence cooling can only be achieved in certain materials with a broad fluorescence spectrum. Raman media, which form an important category of lasing materials, do not have a fluorescence band. Thus, a different approach is needed to intrinsically mitigate the heat dissipation in Raman lasers.

To that aim, we recently developed an original technique, which works as follows: The lasing mechanism of a Raman laser is stimulated Stokes Raman scattering (SSRS), where a pump photon is converted into a lower energy Stokes photon and a phonon or heat, the so-called quantum-defect heating. We have theoretically demonstrated that, in the case of phase matching, CARS converts a pump photon and an anti-Stokes photon, while extracting quantum-defect heating from the Raman medium. This is very different from the most common interpretation of CARS, where it is seen as a mechanism that does not exchange energy with the medium. By using these “novel” photon and phonon balances of CARS, one finds that the quantum-defect heating in a Raman laser will decrease if the ratio of the number of anti-Stokes photons to the number of Stokes photons, coupled out of the Raman laser, is increased. The latter forms the basic principle of our intrinsic heat mitigation technique.

Besides introducing this concept, we have also developed several methods to enhance the heat mitigation efficiency. Finally, by using our Raman laser modeling formalism, we have numerically demonstrated for a mid-infrared silicon Raman laser that our technique can reduce the quantum-defect heating as much as 35 percent.

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References