Second Stokes oscillation and Raman gain-guiding in micro-lensed monolithic diamond Raman lasers

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Compact monolithic diamond Raman lasers (DRL) are an attractive alternative for wavelength conversion from green to yellow in comparison with tunable laser / OPO systems. Laser sources emitting in yellow-red spectral range can be used to form a detailed and tissue-specific image using the photoacoustic technique. Results of broadening of the colour palette available with a monolithic DRL and analysis of Raman beam formation mechanisms in these devices will be presented.

The possibility of extending the spectral coverage of a monolithic DRL to the red spectral range, corresponding to the 2nd Stokes emission at 620 nm when pumped at 532 nm, was studied on a 2 mm long micro-lensed diamond device with the radius of curvature of the micro-lens being 13 mm. The pump pulse duration was 1.5 ns at a repetition rate of 10 kHz, and pump spot radii of 21, 12 and 8 µm were used (Fig. 1 (a-c)). The highest conversion efficiency of 63% from the pump (532 nm) to the 2nd Stokes (620 nm) was observed with the pump spot radius of 8 µm (Fig. 1 (c)). This efficiency was reached at a pump peak intensity of 4.5 GW/cm^2. The maximum 2nd Stokes output power reached 68.3 mW for a maximum pump power of 126 mW with the pump spot radius of 8 µm. At that pump power level 3rd Stokes oscillation (676 nm) was observed as well with the maximum output power reaching 32.6 mW. The slope efficiency of the 2nd Stokes output power (solid lines in Fig. 1 (a-c)) increased from 41% with the 21 µm pump spot radius to 71% with the 8 µm pump spot radius. The intracavity 2nd Stokes Raman mode size was measured to help understand this effect. It was found to be half that expected from ABCD matrix calculations (Fig. 1 (d-f)). This discrepancy is found to be consistent with Raman gain-guiding. In this regime, the resonator mode radius ω_D can be calculated as: $\omega_D = \sqrt{\omega_P \sqrt{\frac{\lambda_s}{2\pi g I_P n}}}$, where ω_P is the 1/e^2 pump beam radius, λ_s is the wavelength of the Raman laser emission in vacuum, g is the Raman gain coefficient, I_P is the pump laser on-axis peak intensity and n is the Raman medium refractive index. The calculation details of the size of the Gaussian duct inside the monolithic DRL will be presented. The calculated radii of the Gaussian duct of the 2nd Stokes emission in the micro-lensed devices are 14, 12.3 and 11.4 µm, for the different pump spot radii ω_p (21, 12 and 8 µm) used in the experimental work. The obtained values are in good agreement with the experimentally measured 2nd Stokes intracavity mode radii (Fig. 1 (d-f)). This suggests that Raman gain-guiding significantly affects beam formation in these lasers.

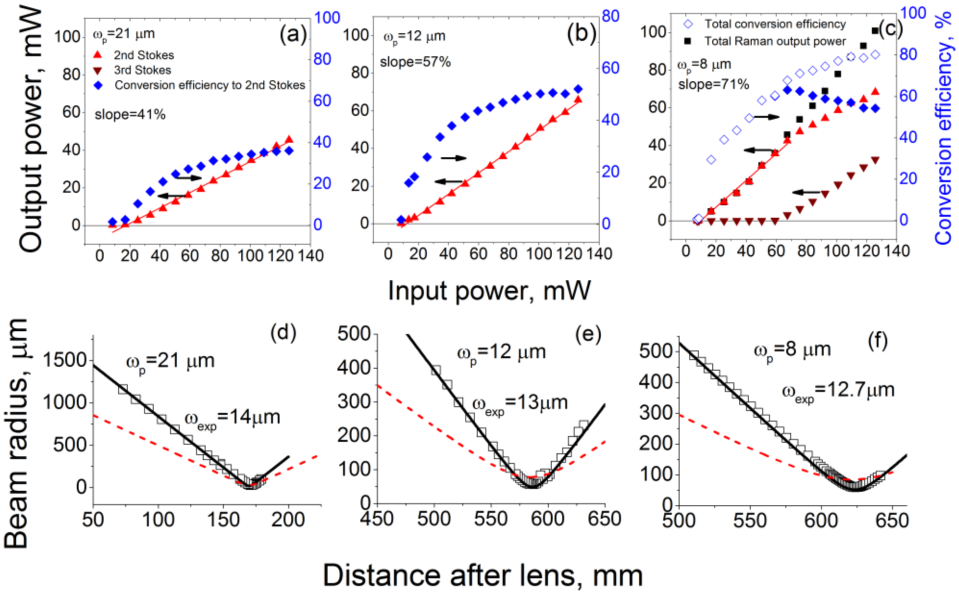

Fig. 1 (a)-(c) Power transfer characteristics of micro-lensed Raman converter for different focusing lenses. Solid lines are the linear fits to the 2nd Stokes output power. (d)-(f) Measured (squares) and simulated (solid lines) radii of the 2nd Stokes beam caustics of the micro-lensed Raman converters for different pump spot radii ω_p. The 2nd Stokes laser mode radii ω_{exp} on the output coupler which were kept as free fit parameters each time are also shown. The red dashed lines are the results of simulations when keeping the 2nd Stokes intracavity Raman beam radii on the output coupler fixed at 24µm (for the 2 mm sample), as expected from the calculation using the ABCD formalism.