Quantum-Enhanced Stimulated Raman Scattering Microscopy for Bioimaging Applications

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Stimulated Raman scattering (SRS) microscopy is a rapidly advancing, label-free imaging technique that visualizes chemical bonds and structural features in biological specimens without relying on fluorescent tags or other invasive agents. By employing pulsed pump and Stokes (probe) beams, modern SRS systems enable real-time, high-speed imaging. However, achieving a high signal-to-noise ratio (SNR) often requires increased optical power, which risks inducing photothermal or photochemical damage to sensitive biological samples. To overcome this limitation, a promising approach involves integrating amplitude-squeezed light into the SRS setup [1, 2]. By replacing one of the beams with amplitude-squeezed light – characterized by noise levels below the shot noise limit at the same given intensity – this method enhances SNR and sensitivity without increasing the average optical power delivered to the sample.

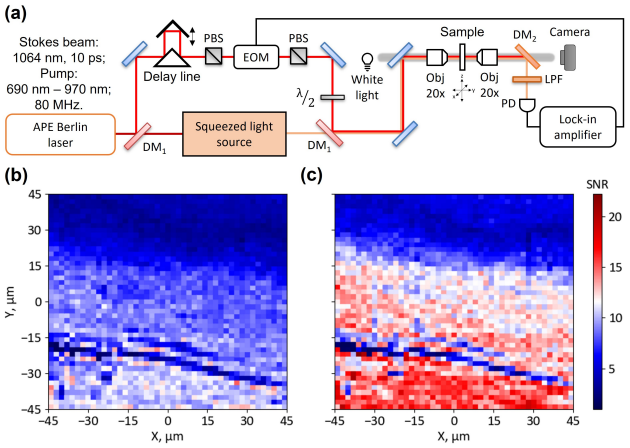

Figure 1: (a) Schematic of the custom-built QE-SRS microscope system. Comparison of the signal-to-noise ratio of SRS signals from pork muscle tissue measured at a Raman shift of 2940 cm^{-1} using (a) a classical Stokes beam and (b) an amplitude-squeezed Stokes beam

In this work, we develop a quantum-enhanced SRS (QE-SRS) microscopy system by utilizing amplitude-squeezed light as the Stokes beam in combination with a tunable coherent pump, enabling access to vibrational modes spanning from 900 cm^{-1} to 3400 cm^{-1}. Using traveling-wave optical parametric amplification (OPA) in second-order nonlinear waveguides, we generate a Stokes beam with 4.9 dB of amplitude squeezing. When this squeezed Stokes beam is combined with the pump in our custom-built QE-SRS microscope on a pork muscle tissue, we achieve an average noise reduction of 3.4 dB and a 44% improvement in SNR (figure 1) – to the best of our knowledge, the largest enhancement reported to date in QE-SRS microscopy applied to biological samples.

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References

[1] R B de Andrade, H Kerdoncuff, K Berg-Sørensen, T Gehring, M Lassen and U L Andersen, Optica **7**, 470 (2020)

[2] C A Casacio, L S Madsen, A Terrasson, M Waleed, K Barnscheidt, B Hage, M A Taylor and W P Bowen, Nature **594**, 201 (2021)