High-Order Raman Scattering Emission in High-Q Factor As_2S_3 Microspheres

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***Abstract*—Cascaded stimulated Raman scattering emission is reported in high-Q As_2S_3 microspheres for the first time. Stimulated Raman scattering emission is observed up to the 5^{th} order with a pump power of $500\ \mu$W at 1550 nm.**

***Keywords*—Microsphere, Optical resonators, Chalcogenide glass, Stimulated Raman scattering**

I. Introduction

Stimulated Raman scattering (SRS) and cascaded SRS are important nonlinear processes especially for the generation of mid-IR signals for biosensing and spectroscopy applications. The small mode volume and high-Q factor of whispering gallery mode (WGM) optical microcavities allow the generation of nonlinear processes such as stimulated Raman scattering with sub-mW input power [1,2]. Cascaded SRS was observed in silica spheres, CaF_2 disks and $LiNbO_3$ disks [2-4]. A WGM cavity made out of a material with a large Raman gain and a broadband mid-IR tranparency window, such as a chalcogenide glass, would be advantageous for these applications. Recently, SRS emission was reported in high-Q As_2S_3 microspheres with an input pump power below 50 μW and at a wavelength of 1550 nm [5]. In this paper, we show the generation of cascaded SRS emission in As_2S_3 microspheres for the first time. Raman scattering emission up to the 5^{th} order is mesured with a pump power of 500 μW at 1550 nm. A self-frequency locked laser setup is used to generate the cascaded SRS.

II. High order Raman emission

A. Sweeping tunable laser

In a first experiment, the emission of a Yenista Optics T100R tunable laser (TLS) is evanescently coupled to an As_2S_3 high-Q microsphere mode using a 2 μm diameter silica tapered fiber. Figure 1 shows the experimental setup. The tunable laser is continuously scanned between 1552 nm and 1554 nm. The SRS emission generated in the microsphere is measured using a Yokogawa AQ6375 optical spectrum analyzer (OSA). The microsphere diameter is 50 μm. The coupling conditions are optimized using a polarization controler (PC). Using the *Hold Max* feature of the OSA, the forward SRS emission spectrum is built through several TLS scans.

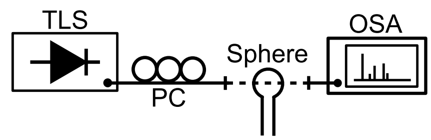

Fig. 1. Stimulated Raman scattering measurement setup using a sweeping tunable laser.

Fig. 2 shows the measured spectra up to the 4^{th} order SRS with an input pump power of 306 μW. Successive Raman emission orders appear $\sim$ 10.3 THz away from its pump wavelength around 1640 nm, 1745 nm, 1850 nm and 1975 nm respectivelty, as expected [6]. Multiple peaks emission is visible and is related to multiple WGM resonances that obey the threshold conditions. The emission peaks can be generated from single or multiple high-Q resonances in the 1552-1554 nm range. A 0.5 nW 5^{th} Raman order peak at 2132 nm is also measured on a similar As_2S_3 microsphere using an input pump power of 500 μW.

B. Self-frequency locking laser setup

In a second experiment, we implemented a self-frequency locking laser setup based on Kieu *et al.* [7]. A self-frequency locking laser setup allows a high-Q resonance of the sphere to remain stable in a continuously lasing state. Thermal drifting of the high-Q resonance is then mitigated. Thermal drift is especially important for As_2S_3 which has a relatively high $\frac{dn}{dT}$.

The experimental setup is shown in Fig. 3. A 1480 nm pump diode emission is sent to a 3 m Erbium doped fiber amplifier. The generated gain emission direction (black arrows) is imposed by an isolator (Iso). When a high-Q resonance is mode-splitted by a small perturbation such as surface roughness, the WGM cavity acts as a mirror and reflects the signal. The lasing wavelength in the fiber loop is selected by the 0.2 nm bandwidth tunable Bragg filter (TBF) and is locked on a resonance of the sphere. A typical high-Q resonance has a full width at half maximum below 1 pm. When the threshold conditions are respected, cascaded SRS is generated in the sphere. The polarization is optimized by two PCs and a polarizer (Pol). The transmitted spectrum of the fiber laser and the forward SRS emission is measured by an OSA.

A measured spectrum is shown in Fig. 4. The fiber laser emission at a wavelength of 1556 nm is used to pump SRS emission up to the 4^{th} order.

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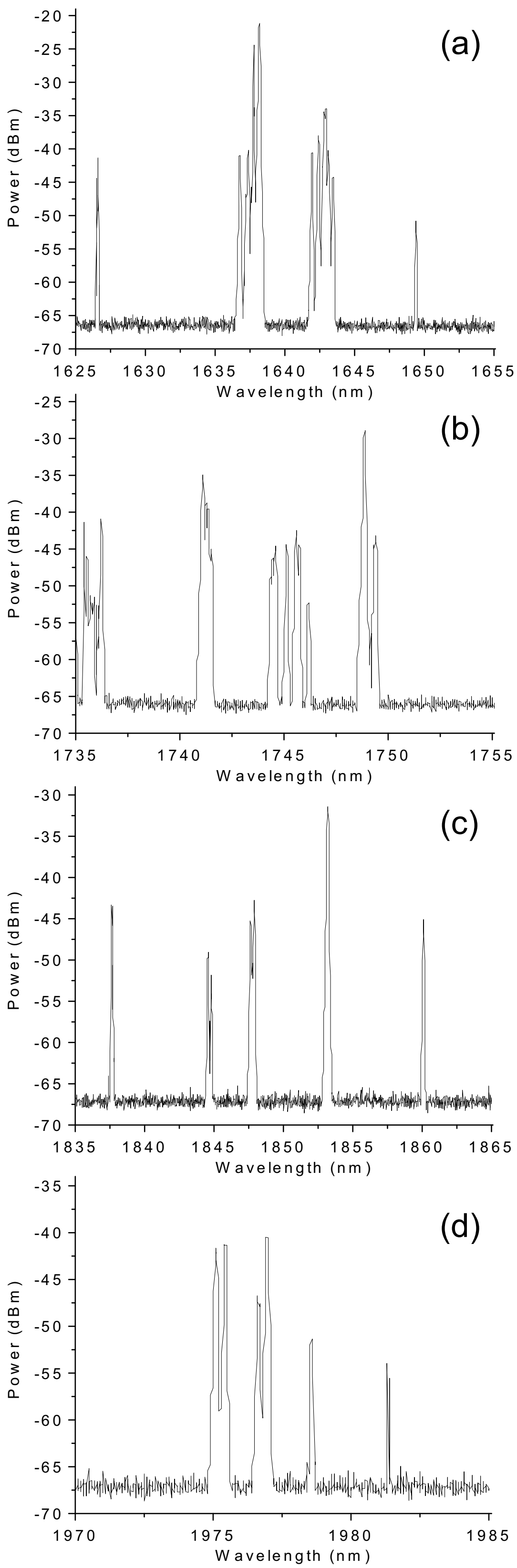

Fig. 2. Stimulated Raman scattering emission spectra of the (a) 1^{th} (b) 2^{nd} (c) 3^{rd} and (d) 4^{th} order for an input pump power of 306 μW.

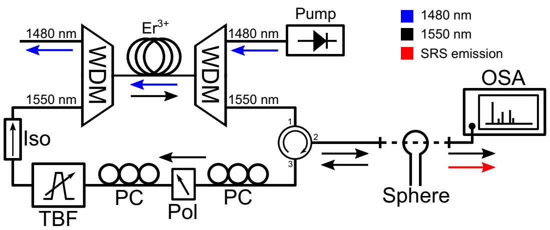

Fig. 3. Self-frequency locking laser setup: a 1480 nm emission (in blue) pumps the 1550 nm emission of the fiber laser (in black). The generated forward SRS emission in the sphere (in red) is measured by the OSA.

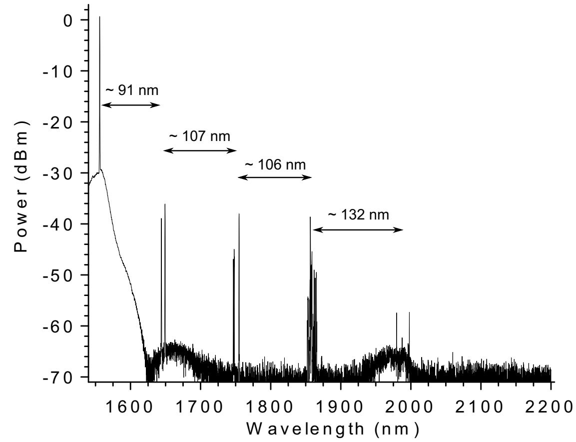

Fig. 4. Cascaded SRS spectrum measured using a self-frequency locking laser setup.

III. Conclusion

We presented the first demonstration of high order stimulated Raman scattering emission in high-Q whispering gallery mode As_2S_3 microcavities. Cascaded SRS emission up to the 5^{th} order was observed with an input pump power of 500 μW. A self-frequency locking laser setup was used to generate SRS emission up to the 4^{th} order. This method combined with high-Q As_2S_3 WGM microcavities could be used to produce low power, compact and stable mid-IR emission sources.

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