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Dennis D. Lowenthal
Yehoshua Y. Kalisky
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Raman Amplification in As-Se Fiber

P.A. Thielen^a, L.B. Shaw^b, P.C. Pureza^b, V.Q. Nguyen^b, J.S. Sanghera^b, and I.D. Aggarwal^b

^aSFA Inc., Largo MD 20774

^bNaval Research Laboratory, Washington DC 20375

ABSTRACT

We have demonstrated Raman amplification in small core As-Se fiber. We observed over 20 dB of gain in a 1.1-meter length of fiber pumped by a nanosecond pulse of ~ 10.8 W peak power at $1.50 \mu\text{m}$. The peak of the Raman gain was shifted by $\sim 230 \text{ cm}^{-1}$ to $1.56 \mu\text{m}$. The Raman gain coefficient is estimated to be about $2.3 \times 10^{-11} \text{ m/W}$, over 300 times greater than that of silica. The large Raman gain coefficient coupled with the large IR transparency window of these fibers shows promise for development of As-Se Raman fiber lasers and amplifiers in the near, mid and long IR spectral regions.

Keywords: Stimulated Raman Scattering, Raman Amplification, Chalcogenide Glass, As-Se

1. INTRODUCTION

Stimulated Raman scattering is an important nonlinear interaction that can be exploited to make lasers and amplifiers. Currently, Raman lasers and amplifiers are available commercially in the $1.5 \mu\text{m}$ wavelength region for telecommunications applications. The use of stimulated Raman scattering allows the manufacture of lasers and amplifiers at wavelengths that are not accessible using traditional rare earth doped materials. However, for applications other than telecommunications, the multiphonon edge of silica glass limits Raman lasers and amplifiers to a wavelength less than $2 \mu\text{m}$. In a search for materials with a large Raman gain coefficient and IR transparency beyond $2 \mu\text{m}$ we have investigated chalcogenide glasses. Chalcogenide glasses are composed of one or more of the chalcogen elements, S, Se, and Te, and other elements such as Ge, As, or Sb to form stable glasses. It has been shown that chalcogenide glasses are chemically durable, possess wide glass forming regions, and can be fabricated into low-loss fiber [1]. These glasses are of interest because of their IR transparency and their potential large nonlinearities. Specifically, in this paper we report on Raman amplification in As-Se glass fibers.

Figure 1 compares the Raman spectra of As-Se and silica glass. As-Se glass has a much narrower Raman line ($\sim 60 \text{ cm}^{-1}$) as compared to silica glass ($\sim 250 \text{ cm}^{-1}$). In addition, the Raman shift for As-Se glass is much smaller ($\sim 230 \text{ cm}^{-1}$) than the Raman shift of silica glass ($\sim 440 \text{ cm}^{-1}$). This smaller Raman shift is often attributed to the larger mass of the As and

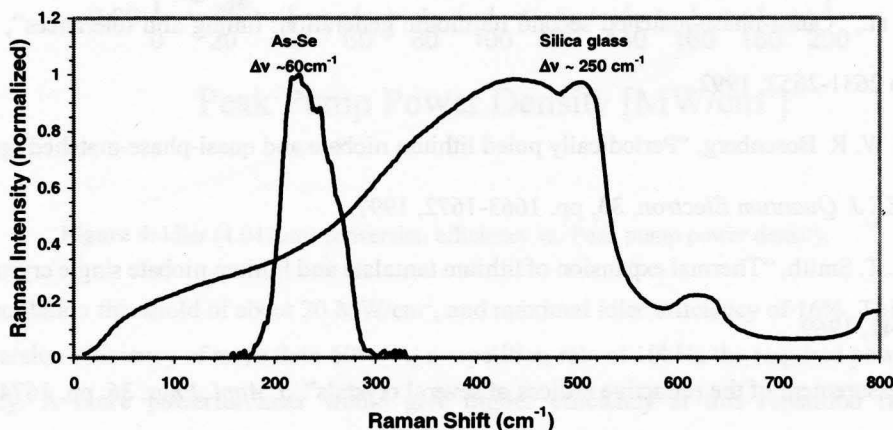


Figure 1: Comparison of As-Se and silica Raman spectra

Se atoms. Previous studies have looked at stimulated Raman scattering in As-S glass, a very similar glass system to As-Se [2]. These studies found the Raman gain coefficient of As-S to be two orders of magnitude higher than that of silica. It was also found that this enhancement in the Raman gain roughly corresponded to the enhancement in the nonlinear index, n_2 . Consequently, one would expect to see an even larger Raman gain coefficient in As-Se since As-Se has an even larger nonlinearity.

2. METHOD AND MATERIAL

The glasses used in this experiment were made from highly purified elemental precursors. The purification techniques and melting procedure are described elsewhere [3]. Using these techniques, rods of $\text{As}_{38}\text{Se}_{62}$ and $\text{As}_{39}\text{Se}_{61}$ were prepared for the core and clad, respectively. These rods were then formed into a fiber using a double-crucible process [4]. A typical loss spectrum of an As-Se fiber is shown in Figure 2. The fiber core was measured to be $7\text{ }\mu\text{m}$ in diameter and the numerical aperture (NA) was measured to be 0.45 at a wavelength of $1.56\text{ }\mu\text{m}$. Note that due to the large NA this fiber is not single mode at this wavelength. The loss of the fiber was also measured at this wavelength using a standard cutback technique. It was determined to be 0.7 dB/m .

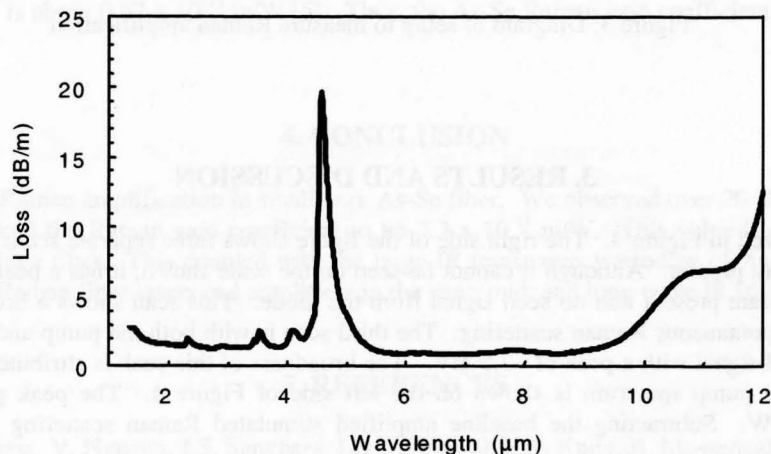


Figure 2: Typical loss spectrum of an As-Se fiber

The experimental setup to measure the Raman gain coefficient of the As-Se fiber is shown in Figure 2. A Continuum Mirage OPO operating at a wavelength of $1.50\text{ }\mu\text{m}$ was used as a pump source. The seed signal to be amplified, a low power $1.56\text{ }\mu\text{m}$ laser diode, was coupled along with the pump source into a 50/50 silica fiber coupler. One of the output ports was butt-coupled to the As-Se fiber. The other end of the As-Se fiber was fed into a Jarrel-Ash $\frac{1}{4}$ -meter monochromator to spectrally separate the pump from the amplified signal. An InGaAs detector and oscilloscope was used to detect the pump and signal. The Mirage OPO outputs $\sim 8\text{ ns}$ pulses at 10 Hz ; therefore all measurements were made when the OPO pulse overlapped temporally with the CW laser diode signal and the corresponding peak powers were used in the calculations.

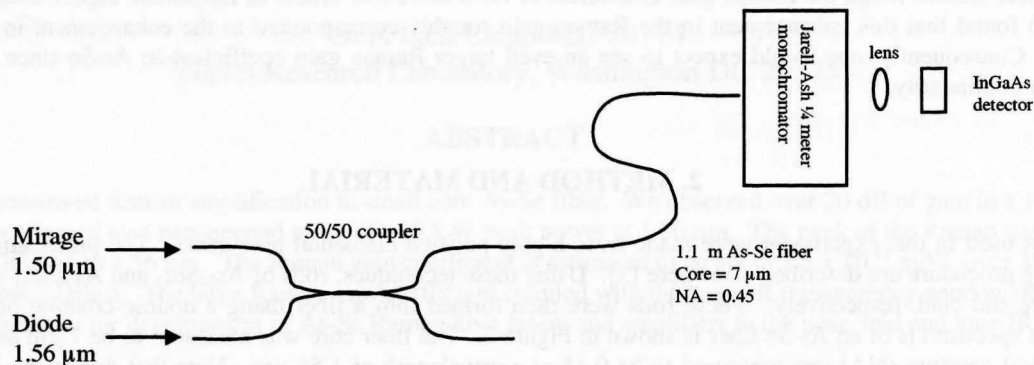


Figure 3: Diagram of setup to measure Raman amplification

3. RESULTS AND DISCUSSION

The results are summarized in Figure 4. The right side of the figure shows three separate scans. The first scan is of the diode with no pump beam present. Although it cannot be seen on the scale shown, it has a peak of 30 μV. The second scan is with the pump beam present and no seed signal from the diode. This scan shows a broad peak of about 1 mV attributed to amplified spontaneous Raman scattering. The third scan is with both the pump and seed signal present and shows the amplified seed signal with a peak of ~7.5 mV. The broadness of this peak is attributed to the ~10 nm FWHM of the laser diode. The pump spectrum is shown on the left side of Figure 4. The peak power of the pump was determined to be 10.8 W. Subtracting the baseline amplified stimulated Raman scattering to make a conservative

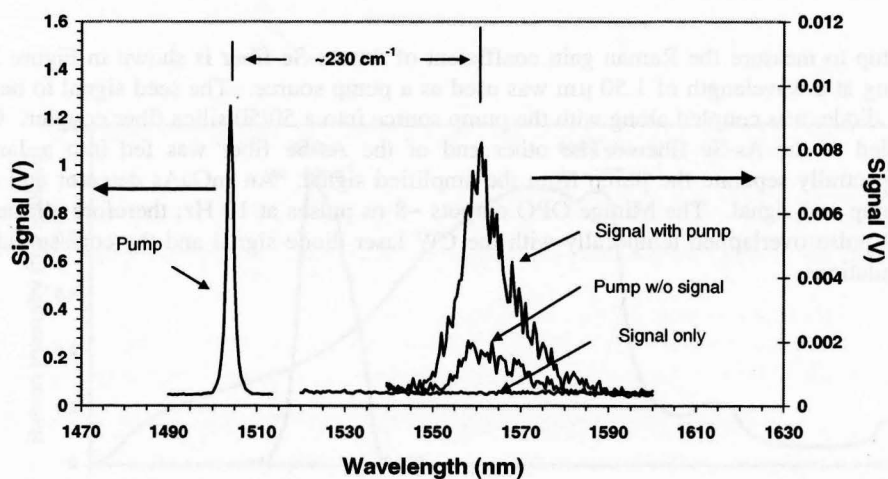


Figure 4: Experimental results showing the spectra of the pump, unamplified signal, background amplified spontaneous Raman scattering, and the amplified signal.

estimate of the gain results in over 20 dB of gain.

The intrinsic measure of Raman gain is the Raman gain coefficient defined in the following equation [5]:

$$G_A = \exp\left(\frac{g_R P_0 L_{eff}}{A_{eff}}\right)$$

where g_R is the Raman gain coefficient, P_0 is the pump power at the amplifier input, A_{eff} is the effective mode area, and L_{eff} is the effective length given by:

$$L_{eff} = \frac{1}{\alpha} (1 - e^{-\alpha L})$$

where α is the loss of the fiber and L is the total length. Since the fiber is multimode the exact modal distribution is not known and the effective area can only be estimated. We estimate that the effective mode field radius is equal to the core radius. Using the above values to calculate the Raman gain coefficient yields $g_R = 2.3 \times 10^{-11}$ m/W. The value of silica fiber at this wavelength is about 0.67×10^{-13} m/W [5]. Thus, the As-Se Raman gain coefficient is calculated to be ~ 340 times that of silica.

4. CONCLUSION

We have demonstrated Raman amplification in small core As-Se fiber. We observed over 20 dB of gain at a wavelength of 1.56 μ m and calculated the Raman gain coefficient to be 2.3×10^{-11} m/W. This value is over 300 times the value measured in standard silica fiber. This coupled with the large IR transparency window of As-Se fibers shows promise for the development of Raman fiber lasers and amplifiers in the near, mid, and long wave IR spectral regions.

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