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Nonlinear optical properties of GeSbS chalcogenide waveguides

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Abstract—**We characterize the nonlinear optical properties of GeSbS chalcogenide glasses with fiber-based experiments. A waveguide nonlinear parameter of 7 W^{-1}/m and nonlinear refractive index of 3.71 × 10^{-18} m^2/W are estimated by self–phase modulation. A GeSbS waveguide could also generate a supercontinuum from 1280 to 2120 nm at the -30 dB level for maximum coupled power of 340 W, showing a 14 fold spectral broadening of the input spectrum explained by cascaded stimulated Raman scattering.**

Keywords- Chalcogenide glasses; Nonlinear optics; Supercontinuum generation

I. Introduction

Chalcogenide glass materials are attractive for nonlinear optical applications because of their high third-order nonlinearities and a wide transmission window in the mid-infrared regime. Two-photon absorption (TPA) and TPA-induced free carrier absorption are also low to moderate in the telecommunication band. Therefore, chalcogenide glasses are highly promising in nonlinear optical signal processing applications.

Chalcogenides consist of chalcogen elements (group 16 in the periodic table) combined with network-forming elements, which enable compositional tuning of properties such as refractive indices, band-edges, and nonlinearity. In particular, Ge–based glasses bonded with heavy metals (e.g. Sb) induce smaller multiphoton spectra in laser and fiber optic applications, therefore, the ternary Ge-Sb-S system (GeSbS) has been widely studied in terms of compositional dependences.

$Ge_{23}Sb_7S_{70}$ films possess a relatively low toxicity and a high degree of alpha radiation hardness. On-chip $Ge_{23}Sb_7S_{70}$ ridge and channel waveguides have been fabricated using photolithography and lift–off [1], and have previously been demonstrated for mid-IR chemical sensing and PbTe–based photodetection [2,3]. However, their nonlinear optical properties using fiber-based experiments have not yet been investigated

In this work, nonlinear optical properties such as nonlinear refractive index and nonlinear absorption of GeSbS are studied in the near–infrared range. Using a 500 fs pulsed laser centered at 1.55 µm, supercontinuum generation extending beyond 2 µm wavelength is achieved, explained by cascaded stimulated Raman scattering.

II. Results and Discussion

The refractive index of $Ge_{23}Sb_7S_{70}$ film is measured to be

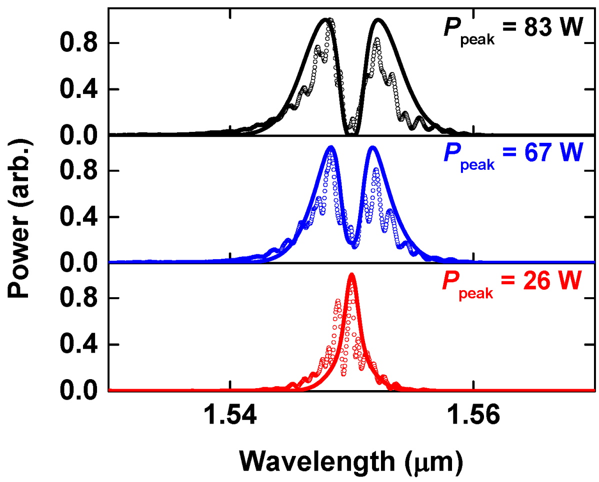

Figure 1. Experimental and theoretical SPM–induced broadened spectra as a function of input peak power. (Solid lines : theory, Circle dots : experimental data)

2.15 at 1.55 µm wavelength and its k-value is observed to be negligible from 600 nm past 25 µm. The bandgap of the film is calculated to be ~ 2.5 eV using Tauc's method, expecting low nonlinear loss at 1.55 µm. The GeSbS waveguide is 15 mm in length, with a height and width of 1.3 µm and 2 µm respectively. The input and output ports of the waveguides possess tapered couplers to facilitate fiber–waveguide coupling [4].

Self–phase modulation (SPM) experiment is implemented to characterize the nonlinear refractive index of $Ge_{23}Sb_7S_{70}$ films. TE-polarized 1.8 ps laser with a 20 MHz repetition rate centered at 1.55 µm is coupled into the waveguide via a polarization-maintaining tapered fiber and the output spectrum is observed using an optical spectrum analyzer. Experimental and theoretical SPM-broadened spectra as a function of input peak power (P_{peak}) are shown in Fig. 1. The experimental bandwidth at the –30 dB level is 18, 31 and 35 nm at P_{peak}= 26, 67 and 83 W, respectively. The nonlinear parameter (γ) is extracted from the best fit between measured and theoretical data based on the nonlinear Schrödinger equation. This parameter, γ, is estimated to be 7 W^{-1}/m, from which the nonlinear refractive index (n_2) is calculated to be 3.71 × 10^{-18} m^2/W at 1.55 µm wavelength, comparable to that measured in microstructured GeSbS fibers (= 2.8 × 10^{-18} m^2/W) [5].

Nonlinear loss is also characterized with a 1.8 ps laser amplified using an erbium–doped fiber amplifier (EDFA). A linear relation between input and output power is observed up to 7 GW/cm^2, that implies the absence of nonlinear loss as shown in Fig. 2. Negligible nonlinear losses could be expected by the material's bandgap of 2 eV; TPA edge is at ~1 µm. Therefore, our GeSbS waveguide can be efficiently utilized in nonlinear optical applications within this wavelength range.

The supercontinuum generation in GeSbS waveguide is also measured using a 500fs laser. The spectral bandwidth measured at –30 dB level is 840 nm, broadens 14 times larger than fundamental pulse at the maximum peak power of 340 W. The supercontinuum spans from 1280 to 2120 nm at –30 dB level, generating beyond 2 µm of wavelength.

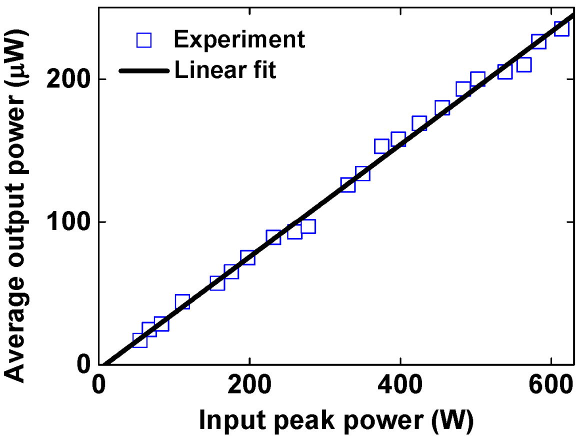

Figure 2. Measured output power as a function of input peak power.

Nonlinear effects which require anomalous dispersion don't come into play as the waveguide operates in the normal dispersion regime (–60 ps/nm/km at 1.55 µm wavelength). Therefore, we predict that stimulated Raman

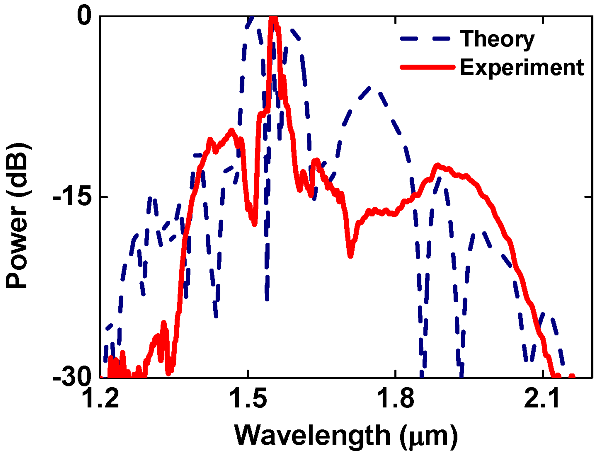

Figure 3. Experimental and simulated supercontinuum spectra at P_{peak} = 340 W.

scattering (SRS) is one contribution to the wideband supercontinuum generation as well as red-shifted side of spectrum. To understand how much the Raman effect influences the spectral output, nonlinear Schrödinger equation including group velocity dispersion, SPM, self-steepening and Raman effects are adopted. By comparing between experimental and theoretical data, both supercontinuum and red-shifted broadening are explained by cascaded SRS as shown in Fig. 3. In this paper, we present GeSbS chalcogenide waveguides featuring relatively large nonlinear parameter, negligible nonlinear losses, and wideband supercontinuum that could be a promising platform for nonlinear optical applications at telecommunication wavelengths.

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References

[1] J. Hu, V. Tarasov, N. Carlie, N.-N. Feng, L. Petit, A. Agarwal, K. Richardson, and L. Kimerling, "Si-CMOS-compatible lift-off fabrication of low-loss planar chalcogenide waveguides, " Opt. Express vol. 15, pp. 11798-11807, September 2007.

[2] Z. Han, P. Lin, V. Singh, L. Kimerling, J. Hu, K. Richardson, A. Agarwal, and D. T. H. Tan, "On-chip mid-infrared gas detection using chalcogenide glass waveguide," Appl. Phys. Lett. vol. 108, pp. 141106, April 2016.

[3] Z. Han, V. Singh, D. Kita, C. Monmeyran, P. Becla, P. Su, J. Li, X. Huang, L. C. Kimerling, J. Hu, K. Richardson, D. T. H. Tan, and A. Agarwal, "On-chip chalcogenide glass waveguide-integrated mid-infrared PbTe detectors," Appl. Phys. Lett. vol. 109, pp. 071111, August 2016.

[4] J. W. Choi, Z. Han, B.-U. Sohn, G. F. R. Chen, C. Smith, L. C. Kimerling, K. A. Richardson, A. M. Agarwal, and D. T. H. Tan, "Nonlinear characterization of GeSbS chalcogenide glass waveguides," Sci. Rep. vol. 6, pp. 39234, December 2016.

[5] J. Fatome et al. "Linear and nonlinear characterizations of chalcogenide photonic crystal fibers," J. Lightwave Technol. vol. 27, pp. 1707-1715, June 2009.