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Abstract

We demonstrate a 70 mol % GeO_2 doped fiber for mid-infrared supercontinuum generation. Experiments ensure a highest output power for a broadest spectrum from 1000nm to 3000nm from this fiber, while being pumped by a broadband 4 stage Erbium fiber based MOPA. Our investigations reveal the unexploited potential of Germania doped fiber for mid-infrared supercontinuum generation. To the best of our knowledge, this is the record power, for an ultra-broadband, all-fiberized, and compact device size supercontinuum light source based on Silica and Germania fiber, ever demonstrated to the date.

Keywords: Fiber amplifiers, Large mode area fibers, Er-doped fibers, High power lasers.

1. INTRODUCTION

Supercontinuum (SC) sources emitting in mid-infrared (Mid-IR) wavelength region are of great importance because this region offers unique opportunities of spectroscopy, imaging, monitoring of several molecular species and gases. The silica-based fibers are limited up to 2.4 μm due to high phonon energy of silica glass. Another alternative option for further broadening is Germania (GeO_2) based glass [1]. Recently, we demonstrated a 1.44 W output power for a broadest spectrum from 700 nm to 3200 nm wavelength region [2]. Yin et al. demonstrated a SC source emitting a 20 dB spectrum from 1944 nm to 3450 nm using a 20 dB input spectrum spanning from 1965 nm to 2666 nm produced by a cascaded source of a TDFA and a 1.9–2.7 μm SC laser source. The germania fiber had a core diameter of 3.5 μm. In order to further scale the output power, Yin et al. used a 8 μm core fiber, however this resulted into lower non-linearity and required an input power of 40 W from thulium doped fiber amplifier to reach 3000 nm [4]. This resulted into a system not suitable for many applications where a low average power source between 2 to 3 μm is required to avoid the damage to samples such as imaging and monitoring etc.

In this report, we report a 9 μm core diameter fiber which is being pumped by a broadband 4-stage Er-Yb fiber based master oscillator power amplifier (MOPA). In order to further extend the input spectrum of MOPA, we use a piece of Tm-doped fiber as a red-shifter. We demonstrate a 20 dB supercontinuum from 1 μm to 3 μm with output power exceeding 5 W, to the best of our knowledge, this is the broadest spectrum ever generated with high power exceeding 1.4 W level from a GeO2 doped fiber. On the other hand, we also produce spectrum spanning from 1.7 μm to 3.4 μm at ultralow power such as 10s of mw with more than 50 % power fraction above 2400 nm wavelength region. This makes these sources suitable for several application where broadband sources at low power are required to avoid the damage of samples.

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2. PUMP SOURCE AND GeO2 DOPED FIBER

An all-fiberized compact 4-stage MOPA was constructed in-house, a diode laser being directly modulated was used as a seed source. The pulse width was fixed to 1 ns (+/- 100 ps) and frequency could be varied from 10 KHz to 20 MHz. The signal was further amplified in 3 stages. Figure 1(a) shows the pump power of final stage and final output power with respect to the pump current. A highest power of 13.17 W was obtained at 34 W of pump power with a nearly 40% slope efficiency. Figure 1(b) shows the output spectrum for three different pump currents 1 A, 4 A, and 8 A corresponding to 0.53 W, 6.39 W, and 13.17 W output power respectively. A heavily Germania doped silica fiber with 9 µm core diameter, with GeO_2 molar concentration of around 70% was used in this work. This fiber was fabricated using optimized modified chemical vapor deposition (MCVD) process at COFT, NTU Singapore. Figure 1(c) shows the schematic of the SC source where the delivery of pump source is spliced to GeO2-doped fiber either directly or via a Tm-doped fiber, the output end of fiber was cleaved to 8 degree.

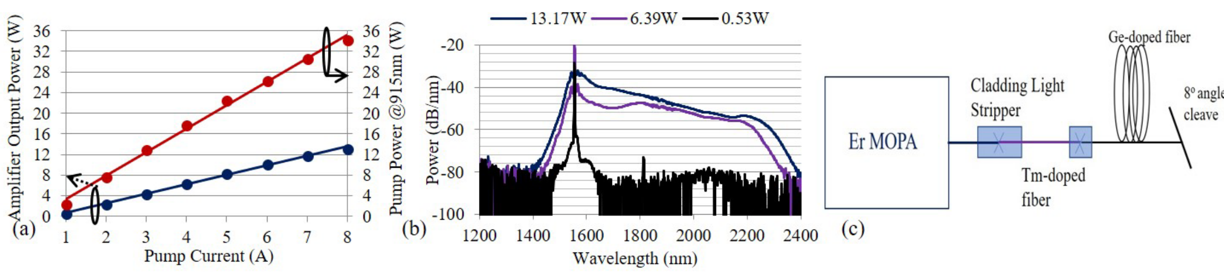

Figure 1(a) Output power and pump power with respect to pump current for a 4-stage Er-fiber based MOPA at 10MHz rep rate (b) output spectrum of Er-MOPA at different output power at 10MHz rep rate and (c) schematic of SC source.

3. SUPERCONTINUUM EXPERIMENTS

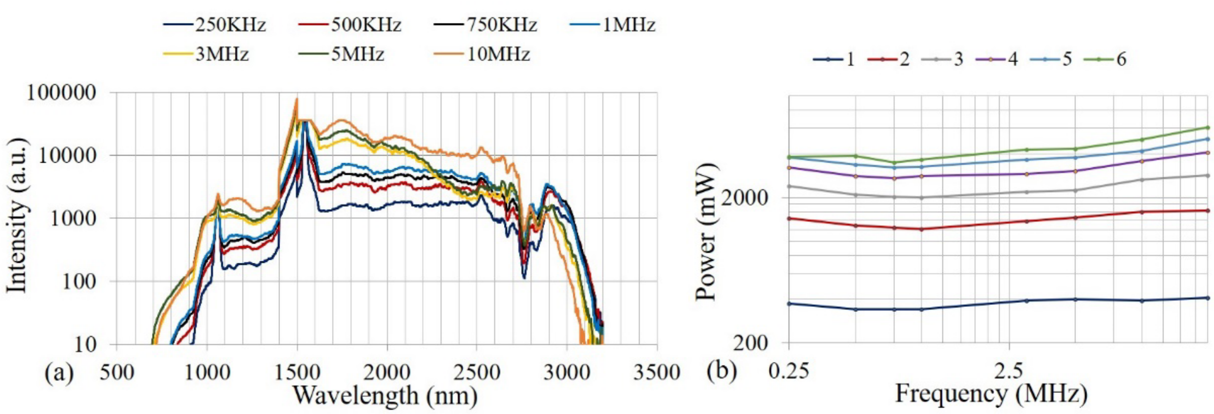

Fig. 2(a) Output spectrum of SC source at 6A pump current (corresponding to output power 8W at 10MHz rep rate) for different rep rates (b) Output power for different rep rates and pump currents.

Figure 2(a) shows the SC spectra obtained for different repetition rate of seed diode of the MOPA at 6A current. Figure 2(b) shows the output power for different rep rates and currents. The length of the fiber is approximately 25cm, several cutbacks were made to reach to this optimum length. A 20 dB bandwidth from ~1000 nm to ~3000 nm can be achieved. The output power up to 6 W at higher rep rates can be achieved. The optimum frequency for broadening is 3 MHz, as there is a trade-off between higher rep rate and peak power. The output power is limited just because of the available input power. To the best of our knowledge, this is best performance of a GeO2 doped for SC generation. In other set of experiments, we spliced a piece of highly Tm_2O_3 doped fiber to the pigtail fiber of MOPA in order to extend the spectrum, now spectrum reaches up to around ~2800nm. Figure 3(a) shows the spectra of a 40 cm long Tm_2O_3 doped fiber and 13.5 cm long GeO_2 doped fiber at different rep rates at 2A, we optimized the length of both fibers using cut-back method. The red edge for 10 and 20 dB bandwidth is approximately 3200 nm and 3300 nm respectively and the blue edge is around 1800nm. The spectra look fairly flat other than absorption peak around 2700 nm. Figure 3(b) shows the spectra at fixed rep rate of 1MHz for different currents, it is interesting to note that, even at very low current such as 1A (output power of SC is ~16 mW and power above 2400nm is ~8 mW), the 10 dB bandwidth is 1900 nm to 3000 nm. This is extremely important of several applications, where a broadband source is required at low power so that damages to the samples under test can be avoided. To the best of our knowledge, this is the first report showing such remarkable (broadband-high power and broadband-low power) SC sources.

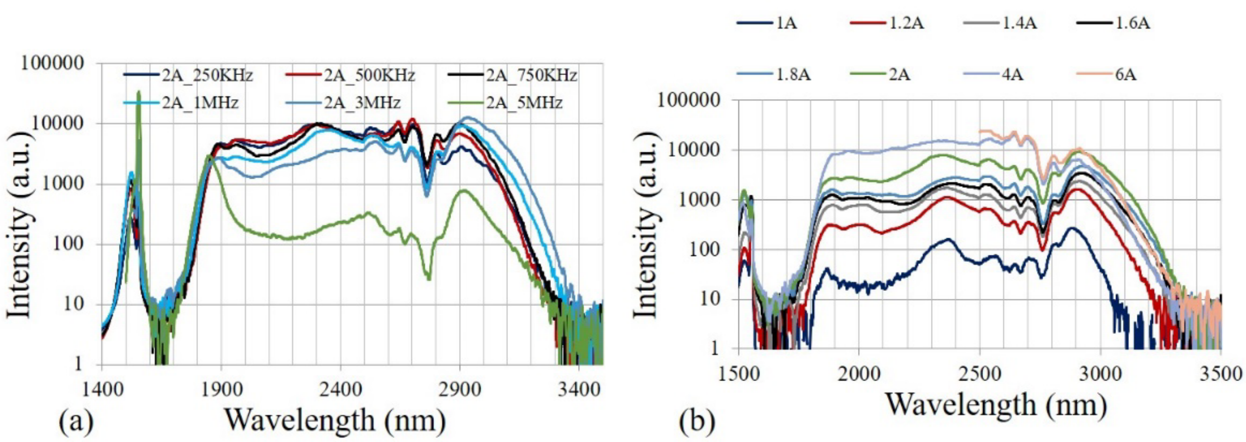

Fig. 3(a) Output spectra of SC source at (a) 2A pump current for different rep rates (b) 1MHz rep rate for different currents.

4. CONCLUSION

We demonstrate highest output power for a broadest supercontinuum source based on Silica and Germania fiber in an all fiberized and compact size device. Our investigations reveal the unexploited potential of Germania doped fiber for mid-infrared supercontinuum generation and surpasses the current state-of-the-art results.

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