Supercontinuum Generation from UV to 3.85 μm in a Fluoride Fiber

Guanshi Qin, Xin Yan, Chihiro Kito, Meisong Liao, Chitrarekha Chaudhari, Takenobu Suzuki, Yasutake Ohishi

Research Center of Advanced Photon Technology, Toyota Technological Institute, 2-12-1 Hisakata, Tempaku, Nagoya 468-8511, Japan and e-mail address: gsqin@yahoo.com, ohishi@toyota-ti.ac.jp

Abstract *We report what we believe to be the first demonstration of supercontinuum generation from UV to 3.85 μm in a 2.5 cm long fluoride fiber pumped by a 1450 nm femtosecond laser.*

Introduction

Since the first report of visible supercontinuum (SC) generation in air-silica microstructure optical fibers with anomalous dispersion at 800 nm in 2000[1], the generation of broadband supercontinua from optical fibers, especially, photonic crystal fibers (PCF), has attracted much attention due to great fundamental interests and numerous applications in laser frequency metrology, optical imaging and spectroscopy[2]. A brief review on commercial products of high power SC light sources expanding from ultraviolet to near infrared spectral region, generated from silica PCFs, may be found elsewhere. Recently, much attention has been paid to non-silica fibers (eg. fluoride, SF6, Bismuth oxide-based, tellurite[3], chalcogenide fibers) with high nonlinearity or low transmission loss at the mid-infrared region for generating mid-infrared SC light sources, which have many advantages in comparison with silica fibers, such as low threshold to initiate the SC processes, short length to generate broadband SC source, and a potential for generating mid-infrared SC light. Very low threshold SC generation has been reported in highly nonlinear chalcogenide nanowire and planar waveguide[4]. In the case of fluoride fibers, Xia et al.[5] reported ultra-broadband supercontinuum generation from 0.8 to 4.5 μm in ZBLAN fluoride fibers by nanosecond diode pumping. In comparison with silica fibers, fluoride fibers not only have high transparency in UV-visible-near infrared region (the transmission window of silica fiber) but also high transparency in mid-infrared region, which has a potential for generating SC light expanding from UV to mid-infrared region. To our best knowledge, SC light expanding from UV to mid-infrared region has not yet been reported in fluoride fibers or any other optical fibers.

In this paper, we reported what we believe to be the first demonstration of SC generation from UV to 3.85 μm in a 2.5 cm long fluoride fiber pumped by a 1450 nm femtosecond laser. Its performance was also compared with that of a 2.5 cm long silica fiber pumped by the same laser.

Experiments

The step-index fluoride fiber (Fiberlabs, in Japan) we used have a core diameter of 9 μm, a NA of 2.0, a zero dispersion wavelength of 1.65 μm.

To measure the SC spectra from fluoride fibers,

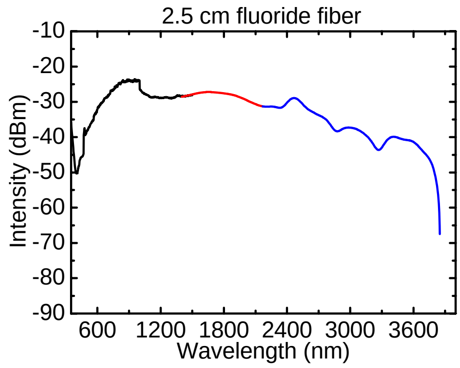
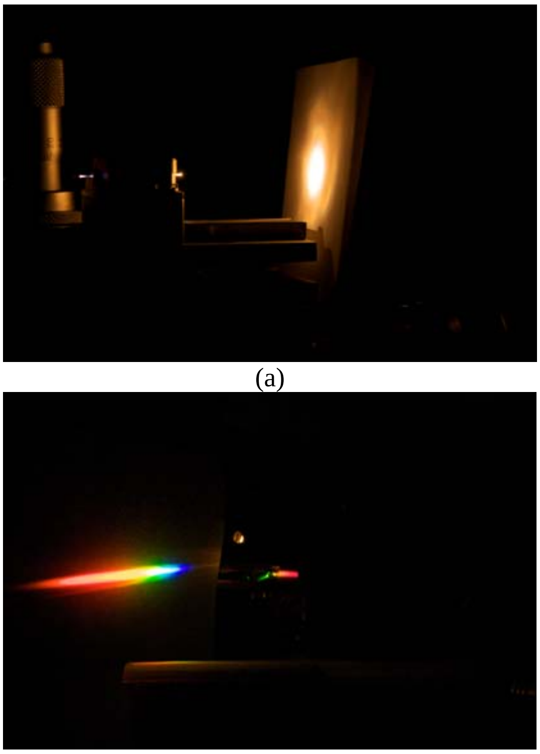


Fig. 1: The measured SC spectra from the 2.5 cm long fluoride fiber when the average pump power of 1450 nm femtosecond laser was fixed at 20 mW.

firstly, both ends of the fiber were cleaved using diamond stylus, checked by using an optical microscope to make sure of good quality of the fiber ends, and were mounted onto the fiber holders. Then we launched 1450 nm femtosecond laser with a pulse width of ~ 180 fs and repetition rate of ~ 1 kHz from a tunable optical parametric amplifier system (TOPAS) pumped by a 800 nm Ti: sapphire femtosecond laser into the input end of a 2.5 cm long fluoride or silica fiber by using a 16× 0.20 NA aspheric lens. Tests with a 2.5 cm long fluoride fiber showed that the launched efficiency, defined as the launched power divided by the power incident on the lens, was about 50 %. The output end of fluoride fiber was mechanically spliced with a fluoride fiber cable with large effective mode field (~ 2010 μm^2) and a NA of 0.25 by using a butt-joint method. The other end with fiber connector of the fiber cable was connected with an optical spectrum analyzer (OSA) with a measurement range of 350~1750 nm (Ando, in Japan) or 1200~2400 nm (Yokogawa, in Japan). The spectrum of longer wavelength region (>2400 nm) were measured by a grating spectrometer, using a cooled InSb detector. The effects of high order diffraction peaks on the measurements were removed by putting the appropriate filters before the measurement systems. The SC spectra were recorded by using those two OSAs and the spectrometer, respectively. Three SC spectra measured by us were spliced directly and presented in the following part.

Results and discussions



(a)

(b)

Fig. 2: (a) The SC generation in short length fluoride fiber and its far-field pattern, (b) The dispersed output of generated SC in short length fluoride fiber.

Figure 1 shows the measured SC spectra from the 2.5 cm long fluoride fiber when the average pump power of 1450 nm femtosecond laser was fixed at 20 mW. It is seen that SC light expanding from UV to 3.85 μm could be generated in short length fluoride fibers, which almost covers the transmission window of fluoride fiber. The average output power of SC light was also measured and about 10 mW. Figure 2(a) shows the SC generation in short length fluoride fiber and its far-field pattern. Figure 2(b) shows the dispersed output of generated SC in short length fluoride fiber. The color of SC light is not pure “white” and slightly yellow due to the relatively weakness of blue part of SC light. The SC generation in short length fluoride fiber is caused primarily by self-phase modulation (SPM) because the pumping wavelength is located at the normal dispersion region and the real fiber length (~2.5 cm) is much shorter than the dispersion length (~2.7 m). The spectrum broadening through SPM[5], ignoring fiber losses, can be approximated by $\delta f \approx n_2 P L_{eff} / A_{eff} \lambda \tau$, where n_2 is the nonlinear refractive index of the fiber core, P is the peak power of the launched pump laser, L_{eff} the effective fiber length, A_{eff} the effective mode area, λ the wavelength of the pump laser, and τ the pump pulse width. In our case, $n_2 = 2.1 \times 10^{-16} cm^2 / W$, $P = 52.2 \times 10^6 W$, $L_{eff} = 2.5 cm$, $A_{eff} = 63 \mu m^2$, $\lambda = 1450 nm$, and $\tau = 180 fs$. So the resulting SPM-generated frequency shift is ~1.67×10^{15} Hz, which corresponds to the spectral broadening range from 172 nm to 3.85 μm when the long-wavelength side is set at 3.85 μm, which covers the whole transmission widow of fluoride fiber. The calculated results suggested that SC light expanding from UV to 3.85 μm in 2.5cm long fluoride fiber pumped by the 1450 nm femtosecond laser was caused primarily by SPM.

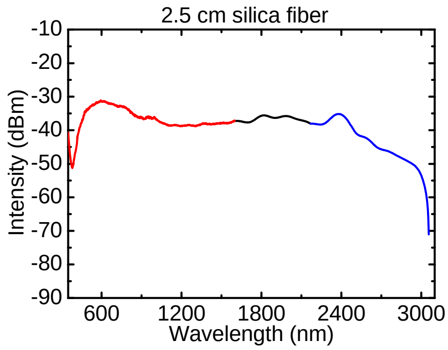


Fig. 3: The measured SC spectra from the 2.5 cm long silica fiber when the average pump power of 1450 nm femtosecond laser was fixed at 20 mW.

As a comparison, we also measured the SC spectra of a 2.5 cm silica fiber (SMF-28) pumped by the same laser, as shown in Fig. 3. It is seen that SC light expanding from UV to 3 μm could be generated from short length silica fibers. In comparison with fluoride fiber, the longe wavelength side of SC light in silica fiber is limited by the transmission window of silica fiber (<3 μm). With further increasing the launched average power of 1450 nm femtosecond laser to 100 mW, we could achieve 44 mW SC light output from 2.5 cm long silica fiber.

Conclusions

In summary, we demonstrated SC generation from UV to 3.85 μm in a 2.5 cm long fluoride fiber pumped by a 1450 nm femtosecond laser. Its performance was also compared with that of a 2.5 cm long silica fiber pumped by the same laser.

Acknowledgement

This work was supported by MEXT, the Private University High-Tech Research Center Program (2006-2010). The authors would like to thank Fiberlabs, Japan, for supplying the fluoride fibers.

References

1 J. K. Ranka et al., Opt. Lett. **25**, 25 (2000).
2 P. St. Russell et al., IEEE/OSA J. Lightwave Technol. **24**, 4729 (2006).
3 P. Delmonte et al., Opt. Express, **16**, 7161(2008).
4 Dong-Il Yeom et al., Opt. Lett. **33**, 660 (2008).
5 Chenan Xia et al., Opt. Lett. **31**, 2553 (2006).