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Supercontinuum generation in pure silica core cut-off shifted single mode fibers

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Abstract: Flat and single mode supercontinuum generation spanning from 700 to 2350 nm was demonstrated using a nanosecond microchip laser and conventional cut-off shifted SMF. This configuration is attractive as a simple and low-cost light source.

OCIS codes: (190.4370) Nonlinear optics, fibers; (320.6629) Supercontinuum generation;

1. Introduction

Broadband supercontinuum light source is attractive for many applications. Compact and low-cost light source consisting of a sub-nanosecond microchip pump laser and photonic crystal fiber (PCF) with a zero dispersion wavelength around 1064 nm has been realized [1] and widely used in many laboratories. Although this configuration shows the best performance so far, further simpler and cheaper light source that realizes broad and flat spectrum is highly anticipated even if it shows less performance in spectrum broadness. One of configurations for such a light source might be a combination of a nanosecond microchip laser and conventional single mode fiber (SMF) instead of PCF. The experimental results in earlier works [2,3] showed relatively broad continuum spectra using nanosecond pulse and conventional SMF or MMF. However, no further detailed study has been done so far, in spite of increasing importance to realize such a simple light source. In this work, we have demonstrated and investigated supercontinuum generation using a microchip laser and conventional cut-off shifted SMF instead of PCF.

2. Experiments and discussion

Figure 1 shows an experimental setup. 1.5 ns pulses from a microchip laser at 1064 nm, with pulse energy 15 mJ and 20 kHz repetition rate were launched into the fibers under test. In the experiment to investigate spectrum evolution with input pump power, the power was controlled using a waveplate and polarizer. Output spectra were measured using two different optical spectrum analyzers to cover entire supercontinuum spectra. The fiber under test was pure silica core cut-off shifted fiber (Sumitomo Electric: Z-fiber^{TM}) which conforms to ITU-T G.654.B. Cut-off wavelength, zero dispersion wavelength, mode field diameter and loss are 1469 nm, 1284 nm, 10.07μm (at 1550 nm) and 0.170 dB/km (at 1550 nm), respectively.

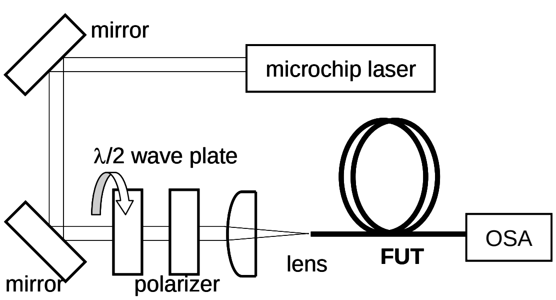

Fig. 1. Experimental setup

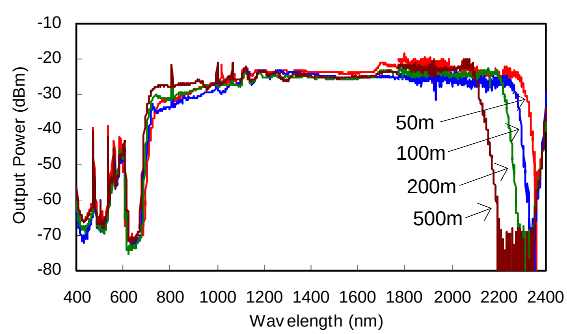

Fig. 2. Supercontinuum spectra with different length of fiber

Figure 2 shows the measured supercontinuum spectra. Broad (700~2350 nm) and flat spectra were obtained. As seen in figure 2, the long wavelength edge shifts to shorter wavelength by increasing the fiber length, while short wavelength edge doesn't shift. This can be understood that the supercontinuum spectra suffered from high infrared absorption loss of the silica based fiber after the evolution of the supercontinuum. It became difficult to obtain broad and flat supercontinuum like figure 2 with the fiber length below about 40 m. From these results, the spectrum evolution occurred within this fiber length and further propagation causes power loss which shrinks bandwidth of the spectrum from longer wavelength edge.

Next, we measured the mode images of the output supercontinuum light below the cut-off wavelength, using a collimating lens, monochromator and CCD camera. As shown in figure 3(d)-(f), the mode images inside the supercontinuum spectrum were Gaussian like fundamental modes even if they were below the cut-off wavelength. On the other hand, outside the supercontinuum spectrum, several peaks were observed in the visible wavelength region (three of them correspond to SHG wavelength of the pump and first two Raman peaks). Actually, the output lights in this wavelength region were observed by naked eye. As shown in figure 3(a)-(c), the modes in visible region were high order mode with concentric shape and at least three different modes were observed. These visible lights would be generated by different mechanism from the supercontinuum.

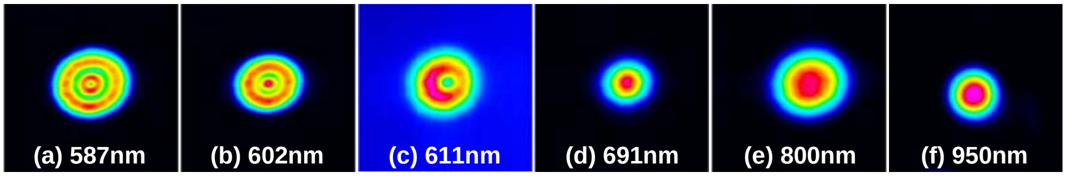

Fig. 3. Observed mode images (a) 587nm, (b) 602nm, (c) 691nm, (d) 720nm, (e) 800nm, (f) 950nm.

Figure 4 shows the spectrum evolution with increasing input power when the fiber length is 100 m. At the low input power (~7 mW), only cascade Raman peaks around 1120, 1180 and 1245 nm are seen. After the 3rd Raman peak grows up, the continuum starts to spread rapidly to longer wavelength side with a small increase of input power, and short wavelength side follows it. These results indicate that parametric process occurs when the spectrum is widely broadening. In order to confirm this, we investigate the group index, because group index is an important parameter especially for the spreading of the continuum spectrum by cascaded four-wave mixing (FWM) process, and the group indices of long- and short wavelength edges of the supercontinuum are the same value in PCF [4-6]. Following this idea, the calculated group index and the edges of the experimentally obtained spectrum are compared, as shown in figure 5. Furthermore, we gave higher attenuation in infrared region by bending all the fiber tightly (~35 mmϕ), and observed that the short and long wavelength edges shifted from 700 to 800, 2350 to 1950 nm, respectively. This spectrum is also shown in figure 5. Consequently, both of measured spectra showed group index matching at the both edges of supercontinuum spectra. From these results, the same mechanism studied in PCF would be applied at the spectrum broadening stage. It should be noted that we have tried same supercontinuum generation using more conventional Ge-doped SMF (cut-off wavelength: 1270 nm, zero dispersion wavelength: 1310 nm), but the obtained spectrum was slightly narrower than cut-off shifted SMF. This may be also explained by the difference in the group index curve.

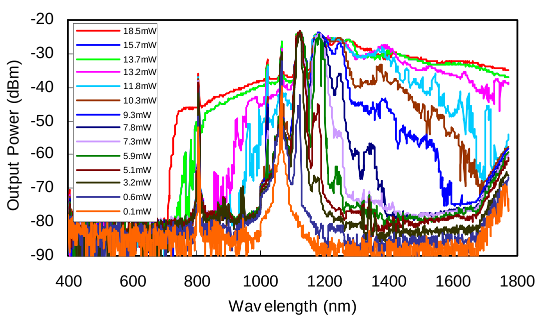

Fig. 4. Spectrum evolution with input power

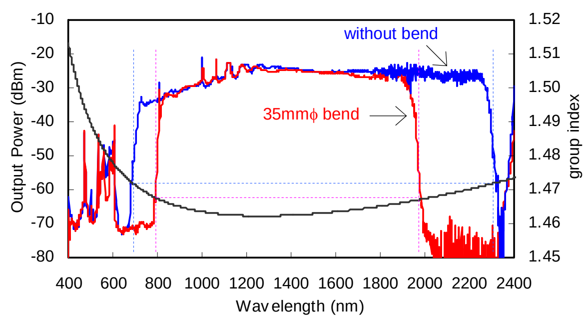

Fig. 5. Comparison of calculated group index and measured spectra

3. Conclusion

Supercontinuum generation using a microchip laser and conventional pure silica core cut-off shifted SMF was demonstrated. We observed single-mode, broad and flat supercontinuum spectrum spanning from 700 to 2350 nm. We showed that group index matching of the long and short wavelength edges plays an important role for broad spectrum evolution. This compact, low-cost and simple light source will be attractive for many applications.

4. References

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