Abstract

Broadband supercontinuum (SC) generation is of great scientific and technical interest, and emerged as one of the best broadband light sources in a range of applications including optical communication, precision spectroscopy, optical coherence tomography (OCT), optical frequency metrology, hyperspectral imaging, light detection and ranging (LIDAR) and, chemical and remote sensing. Hence the broadband SC generation is of strong motivation.

Supercontinuum (SC), is a process of generating broadband optical spectrum by launching optical pulses into a nonlinear medium, continuous interaction of laser pulses with nonlinear optical medium leads to the emission of a wider optical spectrum with a bandwidth many times greater than the bandwidth of the launched pulses. The key nonlinear physical phenomena involved in this processes are stimulated Raman scattering (SRS), modulation instability (MI), cross-phase modulation (XPM), self-phase modulation (SPM), four-wave mixing (FWM) and soliton related dynamics. The SC generation compromises of two parts: a seed laser and a nonlinear medium. The seed laser can generate femtosecond (short) pulses, picosecond or nanosecond (long) pulses or even continuous-wave (CW) laser. The nonlinear media such as normal single-mode-fiber (SMF) or specialty fibers such as highly nonlinear fiber (HNLF), highly nonlinear photonic crystal fiber (PCF), tapered fibers and soft-glass fibers like ZBLAN (ZrF4-BaF2-LaF3-AlF3-NaF). In this project, the carbon-nanotube (CNT) based saturable absorber (SA) is used for the realization of passively mode-locked femtosecond erbium-doped fiber laser (EDFL) as a seed to the specialty fibers, to generate the broadband SC generation and also to study the different aspects of spectral broadening phenomena inside each specialty fiber. Therefore, this thesis focuses on the generation of CNT-SA-based passively mode-locked femtosecond EDFL and generation of broadband SC spectrum from specialty fiber.

The CNT-SA based passively mode-locked EDFL has achieved a pulse width of 620 fs with a pulse repetition rate of 18 MHz at a centre wavelength of 1565 nm with a 3-dB bandwidth of 5 nm. The mode-locked 10 % output pulse peak and average power are observed as 0.21 mW and 18.5 W respectively at the stable mode-locked condition. Throughout this project, the CNT-SA based passively mode-locked femtosecond EDFL is used as seed laser to broadband SC spectrum from all the all specialty fibers. For efficient activation of nonlinear phenomena inside each specialty fiber and, also to study the variation of spectral broadening with respect to the variation in input pulse power, the pulse power is further boosted through the amplification using a pulsed erbium-doped fiber amplifier (EDFA).

The spectral broadening inside a 60-meter-long PCF with respect to the variation in input pulse power is observed. The input power to the PCF is varied from 0 dBm to 20 dBm and achieved a maximum SC spectrum bandwidth of 1050 nm from the output of PCF spanning from 1080 nm to 2130 nm. In the next step, the spectral broadening inside the HNLF is studied with respect to the variation in input pulse power from 0 dBm to 20 dBm and obtained a maximum SC spectrum bandwidth of 1400 nm covering from 1100 nm to 2500 nm. In addition to input pulse power variation, here the length of HNLF is also varied and studied the effect of the length variation on spectral broadening and SC spectrum bandwidth.

In order to overcome the limitations of silica-based fibers and to extend the SC spectrum further towards mid-infrared (mid-IR) side, soft-glass ZBLAN fiber is considered. The input pulse power to a 25-meter-long ZBLAN fiber is varied from 0 dBm to 25 dBm. A maximum SC bandwidth of 2000 nm spectrum extending from 1100 nm to 3100 nm is observed from the output of ZBLAN fiber. The SC spectrum variation in the new kind of fiber i.e. in the tapered fibers is studied by applying to taper to the HNLF.

Publications List

Journal Publications

1. **Sivasankara Rao Yemineni,** W. J. Lai, A. Alphones and P. Shum *"*Mid-IR supercontinuum generation in a single-mode ZBLAN fiber by erbium-doped fiber laser" **[Accepted with minor revisions, Journal of Optical Engineering].**
2. **Sivasankara Rao Yemineni,** W. J. Lai, A. Alphones, P. Shum and Betty Meng Zhang, *"*Broadband supercontinuum generation in PCF, HNLF and ZBLAN fiber with a carbon-nanotube-based passively mode-locked erbium-doped fiber laser," **[Under review, JOSA-B].**
3. **Sivasankara Rao Yemineni,** W. J. Lai, A. Alphones and P. Shum, "Broadband supercontinuum generation in sub-meter length of HNLF with a carbon-nanotube based passively mode-locked femtosecond fiber laser*,"* **[Under revisions].**
4. **Sivasankara Rao Yemineni,** W. J. Lai, A. Alphones and P. Shum, "Tapered fibers for flat and broad supercontinuum generation", **[Under preparation]**

Conference Publications

5. **Sivasankara Rao Yemineni,** W. J. Lai, A. Alphones, and P. Shum, "Mid-IR supercontinuum generation in a single-mode ZBLAN fiber pumped by a carbon-nanotube-based passively mode-locked erbium-doped femtosecond fiber laser ", ***Proc. SPIE 10516***, Nonlinear Frequency Generation and Conversion: Materials and Devices XVII, 105160N (15 February 2018); doi: 10.1117/12.2285315.
6. **Sivasankara Rao Yemineni,** W. J. Lai, A. Alphones, and P. Shum, "Flat broadband supercontinuum generation in a short length of highly nonlinear fiber pumped by a femtosecond carbon-nanotube based passively mode-locked erbium-doped fiber laser", ***Proc. SPIE 10516***, Nonlinear Frequency Generation and Conversion: Materials and Devices XVII, 105160A (15 February 2018); doi: 10.1117/12.2283385.
7. **Sivasankara Rao Yemineni,** W. J. Lai, A. Arokiaswami and P. Shum, "Broadband supercontinuum generation in photonics crystal fiber pumped by femtosecond carbon-nanotube-based passively mode-locked erbium-doped fiber laser," ***2017 Progress in Electromagnetics Research Symposium - Fall (PIERS - FALL)***, Singapore, 2017, pp. 2993-2995.doi: 10.1109/PIERS-FALL.2017.8293647.

8. **Sivasankara Rao Yemineni,** A. Alphones and P. Shum, "Broadband supercontinuum generation in highly nonlinear fiber with carbon-nanotube-based passively mode-locked erbium-doped fiber laser," ***2017 IEEE Photonics Conference (IPC),*** Orlando, FL, 2017, pp.263-264. doi: 10.1109/IPCon.2017.8116097.
9. **Sivasankara Rao Yemineni,** A. Alphones and P. Shum, "All-fiber femtosecond laser pulse generation at 1.55 µm and 2 µm using a common carbon-nanotube based saturable absorber," ***2017 Conference on Lasers and Electro-Optics Pacific Rim (CLEO-PR),*** Singapore, 2017, pp. 1-2.
10. **Sivasankara Rao Yemineni,** H. H. Liu and K. K. Chow, "Carbon-nanotube-based passively mode-locked erbium-doped fiber laser for broadband supercontinuum generation," ***2015 10th International Conference on Information, Communications and Signal Processing (ICICS),*** Singapore,2015, pp.1-4.doi: 10.1109/ICICS.2015.7459877.
11. ***Sivasankara Rao Yemineni,*** *W. J. Lai, A. Alphones and P. Shum,* "Tapered fibers for flat and broad supercontinuum generation", ***2017 IEEE Photonics Conference (IPC),*** *Orlando, Florida, USA-2017 [Non-Archived poster presentation]*.