L.7: Development of efficient ultrafast stimulated Raman scattering source at 1120 nm

In all-fiber amplifier systems, the energy scaling of ultrashort pulses is usually limited by the nonlinear effects, particularly due to the onset of stimulated Raman scattering (SRS) and hence efforts are made to increase the threshold for SRS generation by sufficiently stretching the ultrashort pulses in time domain under the chirped-pulse amplification (CPA) scheme. However, in recent time attention has also been paid to enhance the SRS signal in fiber oscillator amplifier systems as it can be exploited as an ultrafast laser source at wavelengths, which are not accessible by doped fibers and solid-state gain media. In the case of Ytterbium-doped fiber (YDF) lasers operating at 1064 nm, the first Stokes shift in silica fiber is generated at ~1120 nm wavelength that corresponds to the expected 13.2 THz Raman frequency shift in silica fiber. In Laser Technology Division, efficient ultrafast SRS at 1120 nm has been generated in Yb-doped all-fiber CPA based multi-stage amplifier setup seeded by mode-locked YDF oscillator. Schematic of the setup is shown in Figure L.7.1.

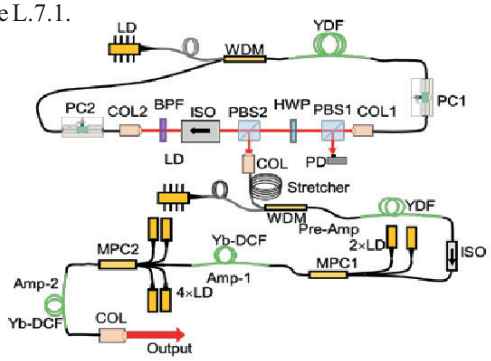

Fig. L.7.1. Schematic of oscillator amplifier setup.

The oscillator consists of a 70 cm long YDF pumped in-core by 976 nm fiber coupled laser diode using wavelength division multiplexer (WDM), polarization controllers (PC1 and PC2), a band pass filter (BPF) at 1060 nm, polarizing beam splitters (PBS1 and PBS2), half waveplate (HWP) and an isolator (ISO). PBS1 placed near collimator 1 (COL1) in combination with PC1 and PC2 acts as a fast-saturable absorber based on nonlinear polarization evolution and PBS2 in combination with HWP acts as a variable output coupler of the oscillator. The oscillator can be easily modelocked by adjusting the PC1 and PC2 and the output signal at PBS2 was coupled into the stretcher fiber (SMF) as shown in the setup. The oscillator generates highly chirped ~5 ps duration pulses centered at ~1060 nm with a spectral width of 10 nm at 40 MHz repetition rate. The stretcher fiber is followed by multistage amplifier setup comprising of a preamplifier (Pre-Amp) and amplifier stages (Amp-1 and Amp-2). The Pre-Amp consists of Yb-doped SMF pumped in core by 976 nm diode laser. The output of Pre-Amp stage was fed into the Amp-1 through an in-fiber isolator (ISO). In Amp-1 and Amp-2, ~2 m and ~4.5 m long Yb-doped double clad fibers (Yb-DCF) were pumped in-clad by two (2×LD) and four (4×LD) multimode fiber coupled laser diodes, respectively with the help of multi-pump combiners (MPC1 and MPC2) with signal feed through. To study the influence of temporal stretching of the pulse in SRS generation during amplification, the stretcher fiber of different lengths 30, 100, and 200 m were used in the experiment. Without stretcher fiber and for more than 100 m long stretcher fiber, significant conversion in SRS was not observed due to either by very large nonlinear effect in short length or due to very less peak power in long length of stretcher fiber.

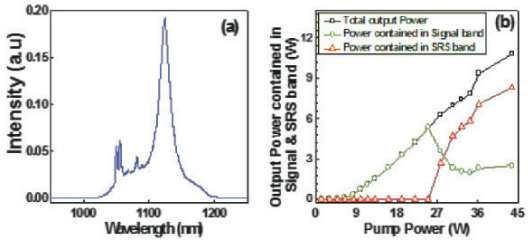

Fig. L.7.2. (a) Optical spectrum at 10.8 W total output power with 30 m length of the stretcher fiber, and, (b) variation of total output power, power contained in SRS band and signal band with input pump power.

In the experiment, among different lengths of stretcher fiber, with ~30 m length, not only a clearly distinguishable first SRS Stokes band at 1120 nm but also maximum conversion of the amplifier output power in SRS band was observed. With 30 m length of the stretcher fiber, at low pump power no contribution from SRS in the spectra was found. However, as the pump power is increased, the SRS signal appears in the spectra once the peak power of amplified signal reaches to some critical value. At ~10 W amplified output power the spectrum shown in Figure L.7.2(a) is dominated by the spectral band at 1120 nm indicating efficient conversion of power from 1060 nm band to the first SRS band. Total output power increases linearly with increase in the pump power as shown in Figure L.7. 2(b). Power contained in the first SRS band was estimated from the recorded output spectra using multi-peak fitting method. At a total pump power of 40 W, the total output power is 10.8 W, out of which 8.4 W of power is estimated to be contained in the first SRS band corresponding to ~77% conversion of the amplified power to the first Stokes band at 1120 nm. It is the highest conversion efficiency and average power to the best of our knowledge obtained in Yb-doped all-fiber amplifier setup without any external seed source at the Stokes wavelength.

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