1:30pm - 1:45pm
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16-Channel x 2.5Gbit/s WDM source using an harmonically and passively modelocked Er/Yb fiber laser

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Compact sources of optical pulses capable of generating high-speed data at multiple wavelengths in the 1550nm fiber optic communication window are critically important technologies for novel optical networks employing a combination of wavelength division multiplexing (WDM) and time division multiplexing (TDM). Producing a comb of wavelength channels from a single broadband source to facilitate wavelength alignment in WDM networks has been proposed as an alternative to using large numbers of individually tunable lasers. A variety of such multi-wavelength comb sources have been demonstrated including spectrally sliced femtosecond sources and semiconductor based devices [1,2,3].

In this paper we demonstrate a simple, compact, and efficient wideband WDM source for soliton or return-to-zero (RZ) transmission. The source generates 16 wavelength channels at 2.5Gbit/sec spaced by 1.6nm. Since the individual bits in the 2.5Gbit/sec streams are short picosecond pulses further bandwidth utilization can be achieved by TDM techniques. The flat spectrum of 30nm 3dB bandwidth covering a wavelength range from 1535 nm to 1565 nm is obtained by amplifying the fs-pulses from a high repetition rate fiber laser and propagating through dispersion shifted fiber (DSF). The configuration was optimized with numerical simulations of the field propagation in the various fiber sections.

The experimental arrangement consisting of a femtosecond fiber laser 2.5Ghz oscillator, several sections of fiber including the Er-doped fiber amplifier (EDFA), and a WDM 16-channel waveguide splitter is illustrated in Figure 1. The fiber laser source, passively modelocked by a saturable Bragg reflector (SBR), generates nearly transform limited pulses of 330fs at an harmonic repetition rate of 2.5Ghz [4]. The laser output optical spectrum is centered near 1550nm with a 3dB bandwidth of 6.5nm. The fiber laser output propagates through a 10m section of SMF (D=16 ps/nm/km) pigtail and is launched into a 20m Er-doped fiber amplifier (EDFA) as shown in Figure 1.

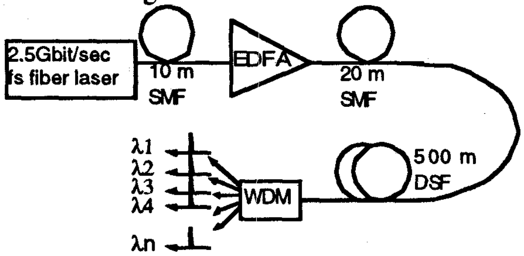

Fig. 1 Experimental configuration

The EDFA is pumped in both directions by two 120mW SDL-980 nm laser. The amplifier gain is approximately 18dB and the average output power is 70nW. A 20m piece of standard single mode fiber (SMF) is spliced to the end of the EDFA to compensate for the strong normal dispersion (D=-25.2 ps/nm/km) in the Er fiber. With nearly zero linear frequency chirp the pulses enter a 500m long section of DSF (D≈-1ps/nm/km @ 1550nm) where the spectral broadening occurs. We use DSF with zero group velocity dispersion (GVD) centered at 1575nm so that propagation occurs in the normal dispersion regime. Propagation in the anomalous regime can lead to soliton effects which cause distortion of the spectrum. Following the DSF section the spectrally broadened output is launched into a 16 channel WDM splitter with 1.6nm channel spacing.

The optical spectrum exiting the DSF has a 3dB bandwidth of 30nm and a flat shape with less than 0.5dB variation in the center 20nm. As shown in Figure 2 good agreement is obtained between the experimentally measured (solid line) and numerically modeled (dashed) output spectra

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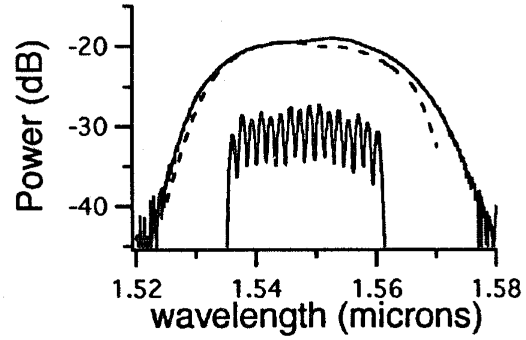

Fig. 2 Experimental (solid) and numerical (dashed) broadened spectrum after DSF, and 16 WDM channels

The 16-channel WDM output is also shown in Figure 2. The nearly 2 dB of intensity variation among the output channels is due to differences in insertion losses between the waveguides in the WDM and not to variations in the spectrum. In Figure 3 the 16 channels of 2.5 Gbit/sec picosecond pulse trains are shown.

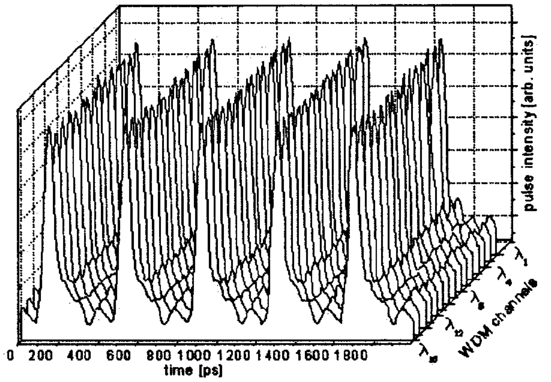

Fig. 3 16x2.5Gbit/sec picosecond pulse trains

The smooth spectral broadening is obtained from the interplay between self-phase modulation (SPM) and GVD in the DSF. In the initial SMF section the pulse propagates in the anomalous dispersion regime and acquires a strong anomalous chirp. In the EDFA which follows, the dispersion is highly normal and as the pulse is amplified, strong SPM occurs. Since the incoming pulses from the SMF to the EDFA have an initial anomalous chirp, the SPM in the EDFA acts to redistribute the blue and red shifted frequencies toward the center of the pulse. This leads to reduced SPM induced spectral spreading than expected. In the next fiber section, SMF is used to almost completely compensate the linear chirp, and pulses entering the DSF section have the necessary short pulse width (~400fs) to broaden the spectrum by SPM.

For the pulse energies and fiber dispersion values used in these experiments SPM dominates over GVD with pulse widths shorter than a few ps. In this regime, an anomalous pre-chirped pulse as the one exiting the 10m of SMF will at its transform limit become spectrally, not temporally compressed in a section of fiber with normal GVD [5]. Under these conditions, it is not possible to considerably compress pulses of a few hundred fs within the DSF section. Thus the most SPM and spectral broadening will occur if pulses with no pre-chirp are launched into the DSF.

Our numerical simulations and experiments show that anomalous pre-chirping produces a jagged spectrum, normal pre-chirping produces a square spectrum, and no pre-chirping produces a smoothed spectrum following propagation in the DSF. While a square spectrum is most desirable, since it wastes little power outside the region used for WDM channels, strong pre-chirping leads to longer pulse durations and diminished spectral broadening. A trade off between the squareness of spectrum and bandwidth must be made. We find this compromise with a slight normal pre-chirp on the pulse accomplished by the EDFA followed 20m of SMF. Once in the DSF, the dispersion acts to increase the duration of the pulse and the strength of the SPM accordingly decreases. The spectral broadening saturates as the pulse duration increases to a few ps.

References:

1. E. A. De Souza, M. C. Nuss, W. H. Knox, and D. A. B. Miller, Opt. Lett., **20**, p.1166 (1995).
2. M. Zirngibl et al., IEEE PTL, **6**, p.1082 (1994).
3. W. T. Holloway, A. J. Keating, and D. D. Sampson, IEEE PTL, **9**, p.1014 (1997).
4. B. C. Collings, K. Bergman, and W. H. Knox, Opt. Lett., **23**, p.123 (1998).
5. M. Oberthaler and R. A. Hopfel, Appl. Phys. Lett. **63**, p.1017 (1993)