# 10 GHz Mode-Locked Ring Laser with External Optical Modulation of a Semiconductor Optical Amplifier

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**Abstract**

We present a novel technique for short pulse generation, based on the externally induced fast saturation of a semiconductor optical amplifier. We demonstrate a 11 ps, 10 GHz fiber ring laser source.

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## Concept

The amplification of a picosecond optical pulse in a semiconductor optical amplifier (SOA) results in the rapid depletion of its gain. A direct consequence of this saturation is a rapid decrease in the carrier density of the amplifier excited state. This in turn results in a rapid variation of the refractive index of the semiconductor and subsequently in phase modulation across the pulse. The phase modulation and chirp produced in an SOA has thus been used extensively for example, for pulse compression or for the demonstration of optical logic gates.

We use the phase and gain modulation, induced by an externally introduced short pulse to the recirculating optical signal in a fiber laser that uses a SOA as the gain medium, to mode-lock the oscillator and produce short pulses without the use of an intracavity, electrically modulated device. Advantages of this novel technique include (a) broad wavelength tuning range determined by the gain profile of the SOA, (b) potential for short pulse generation due to the SOA induced chirp on the circulating pulse (c) stability, due to the drastic reduction of the polarization sensitivity in the oscillator by avoiding strongly polarization sensitive intra-cavity elements such as Li:Niobate modulators, and (d) nearly constant pulsewidth across the source tuning range, determined by the pulse width and power of the externally introduced optical pulse.

We have used this technique to demonstrate a relatively simple, stable, 10 GHz mode-locked source, generating routinely 20 ps pulses with a tuning range of 16 nm and as short as 11 ps pulses.

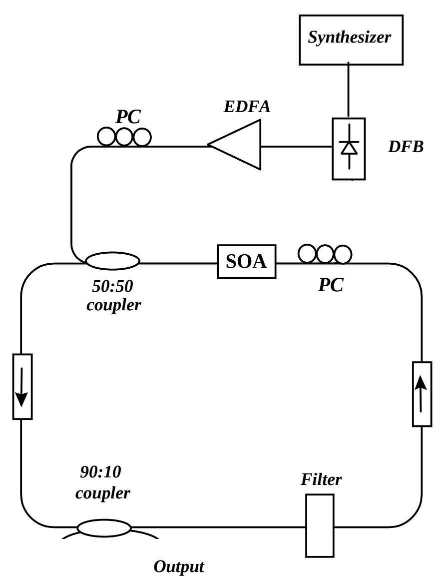


***figure 1:*** *Experimental set-up*

## Experiment, results and discussion

Figure 1 shows the experimental layout. All the components used in the cavity are pigtailed with standard single mode fiber. Gain was provided from a bulk, 500 μm InGaAsP/InP ridge waveguide SOA. The waveguide facets were angled at $10^o$ and were antireflection coated. The SOA had a peak gain at 1535 nm and could provide 23 dB small signal gain with 250 mA dc drive current. Faraday isolators were used at the input and output of the SOA to ensure unidirectional oscillation in the ring and to stop the externally introduced signal from circulating in the cavity. Immediately after the SOA, a 3 dB fused optical fiber coupler was used for the insertion of the pulsed external signal. A 10 dB fused output fiber coupler was used to obtain the output from the source. A tunable filter with 0.6 nm bandwidth was used for wavelength selection. As the SOA exhibited a 2 dB gain dependence, a polarization controller was introduced initially at its input port. The total length of the ring cavity was 18.2 m corresponding to, 10.99 MHz fundamantal frequency. The external signal was provided from a gain switched DFB laser at 1548.5 nm, which produced chirped 50 ps pulses. The output of the DFB laser was amplified in an EDFA and its polarization was controlled for optimum performance before entry into the ring.

With no input on its external modulating port, the laser runs cw and tunes between 1523 nm and 1576 nm providing approximately constant 39 μW output power across its tuning range. With the external source on and the EDFA adjusted to provide 360 μW into the cavity, the ring laser breaks

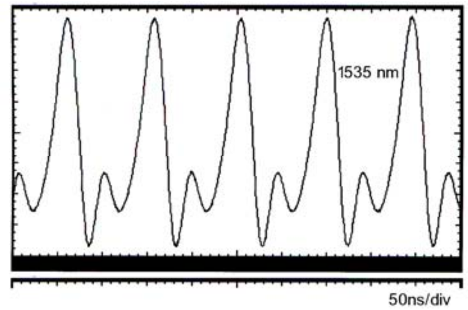


***figure 2**: 10 GHz Pulse train. The time base is 50 ps*

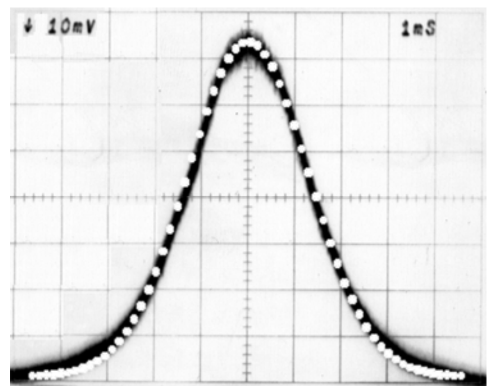


***figure 3**: Autocorrelation trace with fitted Gaussian profile, corresponding to 19 ps pulsewidth. The time base in the trace corresponds to 16.6 ps*

into stable, mode-locked operation once the frequency of the synthesizer driving the DFB is adjusted to a cavity harmonic.

Figure 2 shows the 10 GHz pulsetrain monitored with a 40 GHz sampling oscilloscope. Figure 3 shows the second harmonic autocorrelation trace obtained at 1535 nm and using the 0.6 nm filter. The figure also shows a Gaussian autocorrelation profile fit for a 20 ps pulse – white dots -, showing a good fit. Figure 4 shows the change of the pulsewidth and of the average optical power of the mode-locked source versus wavelength, indicating nearly constant pulsewidth across the tuning range. In order to examine the

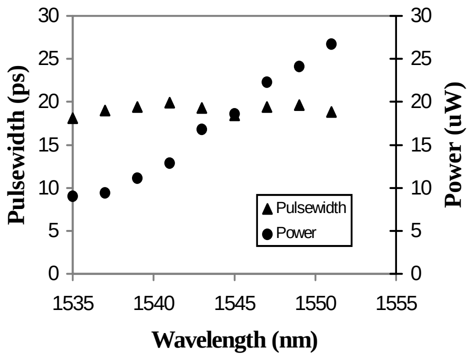


***figure 4****: Variation of the pulsewidth and output power vs Wavelength*

bandwidth limitation and limitation in obtaining short pulses on the optical filter, a 2.4 nm element was used. The autocorrelation trace is shown in figure 5, together with a Gaussian fit and corresponds to 11 ps pulsewidth.

All of the above results were obtained easily and both polarization controllers were only necessary for detailed optimization. Once set the laser source was stable, it required no further adjustments and there was no degradation of the quality of the pulses over long periods of time. In order to examine the quality of the pulses on the polarization state of the external and recirculating signals, both controllers were varied from their optimum position. This resulted in a variation of up to 20 % in the output power and a 25 % pulse broadening, but at no time was there a mode-locked pulse train loss.

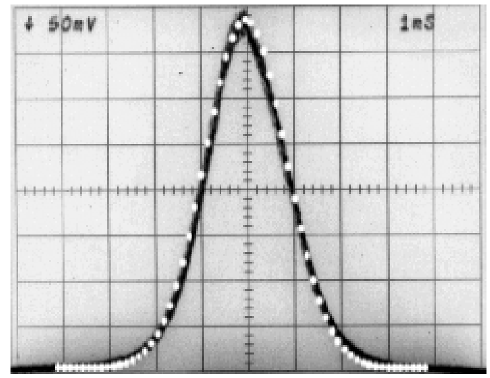


***figure 5****: Autocorrelation trace with fitted Gaussian profile, corresponding to 11 ps pulsewidth. The time base in the trace corresponds to 16.6 ps*

## Conclusions

We have demonstrated a novel technique for short pulse generation, using the saturation properties of a SOA by an externally introduced short pulse. We have used this technique to demonstrate a stable, low polarization sensitivity, mode-locked fiber ring laser, generating 20 ps pulses with a 16 nm tuning range at 10 GHz and as short as 11 ps pulses.

## References


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