Coherent Spectral Broadening and Compression of a Mode-locked VECSEL

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Abstract: We report the coherent spectral broadening of a mode-locked VECSEL in normal-dispersion photonic crystal fibers. Subsequent compression produced 150 fs pulses at 270 mW average power or 220 fs pulses at 520 mW average power.
OCIS codes: (320.7090) Ultrafast lasers; (320.5520) Pulse compression; (140.5960) Semiconductor lasers

1. Introduction

Recent demonstrations of femtosecond mode-locked VECSELs with Watt-level output powers [1, 2] have fuelled interest in their possible use as seed sources for gigahertz-mode-spacing supercontinuua. To date, however, while VECSELs have been used for supercontinuum generation both directly [2] and in fibre-amplified configurations [3], the majority of the resulting supercontinuua have been incoherent, primarily as a result of the pulse durations of the VECSEL seeds, which are typically in the few-hundred femtosecond range rather that the sub-200-fs pulses which would be suitable for coherent supercontinuum generation when soliton effects are present. While sub-100-fs pulses have been demonstrated in low power mode-locked VECSELs [4], similar pulse durations at average powers approaching 1 W remain elusive.

This paper describes the experimental demonstration of an alternative route to achieving high power, sub-200-fs pulses at gigahertz repetition rates. Coherent spectral broadening of a 455 fs, 1.4 W VECSEL is performed in photonic crystal fiber in the normal dispersion regime [5, 6], followed by pulse compression. The resulting 1.55 GHz source yields either 150 fs pulses at 270 mW average power or 220 fs pulses at 520 mW average power.

2. Results and discussion

The gain sample used in this work was an antiresonant design, grown by NAsP III-V GmbH, containing 10 InGaAs quantum wells in an 11λ/2 long microcavity designed for operation at 1015 nm. The sample was flip-chip bonded to a 0.3 mm thick diamond heatspreader which was mounted on a water-cooled copper block. The laser cavity was formed between a 1.45 % output coupler with 100 mm radius of curvature and a surface recombination SESAM, with the gain sample as a folding mirror. The gain sample was pumped with up to 25 W in a 300 μm diameter spot using a fibre-coupled 808 nm diode system, and the ratio of mode areas on the gain sample and SESAM was estimated to be 2:1. The SESAM heatsink was held at a temperature of 16 ºC by a thermoelectric cooler and the gain sample heatsink temperature at 17 ºC. The laser output, at an average power of 1.4 W and a repetition rate of 1.55 GHz, was characterized using a 10 GHZ bandwidth RF spectrum analyzer, which confirmed stable modelocking, and a MesaPhotonics FROGscan FROG system. The measured FWHM pulse duration and spectral bandwidth were 455 fs and 3.4 nm centred at 1007 nm, corresponding to a time-bandwidth product of 0.46.

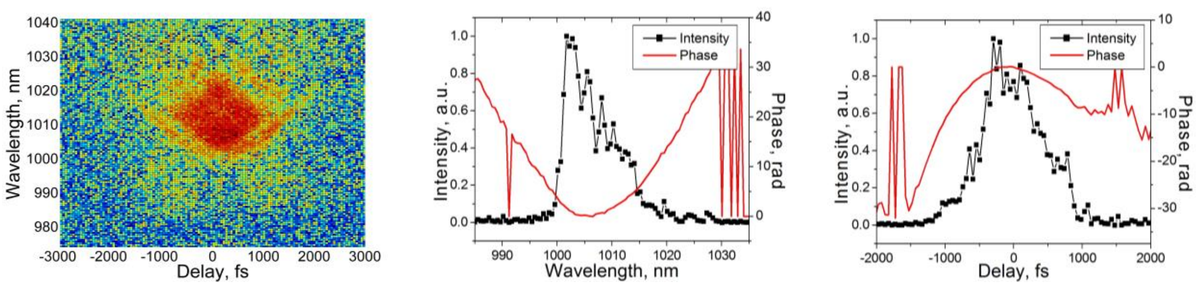

Figure 1, FROG spectrogram (a), and extracted spectral (b) and temporal characteristics (c) of the 650 mW output from the University of Bath fiber. Close-to-parabolic phase profiles can be seen in both spectral and temporal domains.

The laser output was launched through an optical isolator into two different pieces of photonic crystal fiber: a 4 m length of all-normal-dispersion fiber produced at the University of Bath (UoB fiber) [7], and a 1 m length of

SC-5.0-1040 fiber from NKT Photonics. The VECSEL wavelength was in the normal dispersion regime for both fibers, which have a dispersion minimum at 1064 nm and a zero dispersion point at 1040 nm respectively. A transmission of 45% was achieved in the case of the UoB fiber, corresponding to an output power of 650 mW from the fiber, but thermal issues with the fiber coupling limited the power output from the NKT fiber to 350 mW. Moderate spectral broadening was achieved in both cases, to 20dB bandwidths of 51 nm and 39 nm respectively. Figure 1 shows a FROG spectrogram of the output of the UoB fiber, along with the retrieved spectral and temporal characteristics. The extracted phase in both spectral and temporal domains is close to parabolic as expected for coherent spectral broadening in the all-normal dispersion regime.

Compression of the outputs of both fibers was performed using a grating compressor with a throughput of ~80%, based around two 1000 line/mm transmission gratings. When set for optimal linear dispersion compensation, FWHM pulse durations of 150 fs and 220 fs could be achieved from the NKT and UoB fibers respectively at average powers of 270 mW and 520 mW. A FROG spectrogram of the compressed output of the NKT fiber is shown in figure 2, along with the retrieved spectral and temporal characteristics.

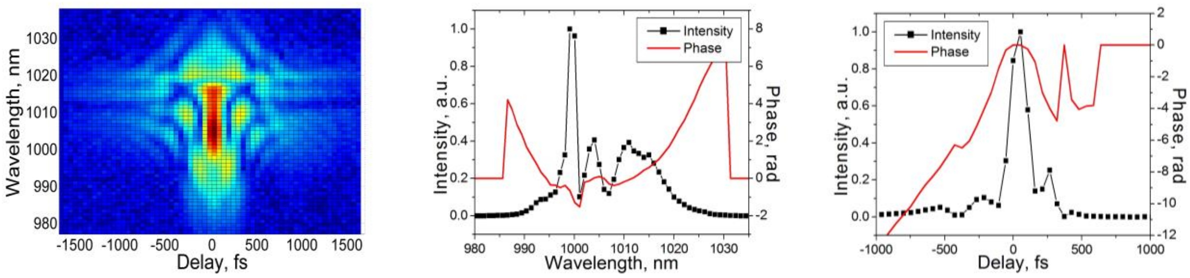

Figure 2. FROG spectrogram (a), and extracted spectral (b) and temporal characteristics (c) of the compressed output of the NKT fiber. A FWHM pulse duration of 150 fs is achieved at an average power of 270 mW.

It is clear that, while the compression has given close-to-linear phase across the main body of the pulse, uncompensated higher-order dispersion has resulted in approximately 20% of the pulse energy remaining in side peaks. The compressed output of the UoB fiber yielded a similar value, but with a longer pulse duration despite its broader spectral bandwidth. It is likely that in both fibers the pulse duration and the energy in the side peaks could be minimized by optimizing the length of fiber used. As such, neither system can yet be considered optimal, with the performance of the NKT fiber based system being limited by poor coupling resulting from thermal issues, and both systems suffering from less-than-complete pulse compression. Improvements in these areas, and of the VECSEL, would be expected to yield further advances in performance.

3. Conclusions

We demonstrate a 1.55 GHz repetition rate pulse source based on coherent spectral broadening and compression of a mode-locked VECSEL. Trains of either 150 fs pulses at 270 mW average power or 220 fs pulses at 520 mW average power are generated.

4. References

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