Apodized Point-by-Point Fiber Bragg Gratings In An All-Optical, Actively Q-switched All-Fibre Laser

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Abstract: We report an all-optical, actively Q-switched, all-fibre laser utilizing an ultrafast laser-inscribed, wavelength-tunable, apodized fibre Bragg grating. The tailored spectrum of the apodized point-by-point gratings enables an order of magnitude improvement in pulse duration.

OCIS codes: (060.3735) Fiber Bragg gratings; (060.3510) Lasers, fiber; (320.7120) Ultrafast phenomena.

1. Introduction

Fiber Bragg gratings (FBGs) fabricated with a femtosecond laser using a point-by-point (PbP) technique possess a number of unique characteristics, giving rise to their increasing popularity for a variety of applications, especially in fiber lasers and sensing [1]. The inscription process relies upon nonlinear photoionization processes, enabling grating inscription into non-photosensitive fibers, including rare-earth-doped fibers. PbP FBGs are also stable at temperatures approaching 1000°C and under intense optical fields, making them highly suitable for high-power laser applications as well as high-temperature sensing. Our recent demonstration of apodized [2], chirped and superstructured PbP FBGs [3] has greatly increased the flexibility of the PbP technique and enables new opportunities for a variety of applications. In this work, we demonstrate the application of apodized PbP FBGs to an actively Q-switched, all-fibre laser system. This unique system relies on wavelength-tunability of a PbP FBG in a Yb-doped fibre by resonant pumping of the Yb ions [4]. The use of apodized PbP FBGs increases the loss contrast achievable in the cavity, which has significant impact on the output pulse duration and average power.

2. The all-optical, actively Q-switched fibre laser

The fibre laser utilized Er-doped single-mode fibre, continuously pumped at 976 nm. The cavity was formed by two PbP FBGs with Bragg wavelengths around 1540 nm—the output coupler inscribed in SMF-28e fibre and the high-reflector inscribed directly into a highly Yb-doped fibre. Repetitive wavelength-tuning of the high-reflector is achieved by resonant optical pumping of the Yb-doped core with a second, modulated 976 nm diode laser. The modulated pump shifts the Bragg wavelength of the high-reflector with respect to that of the output-coupler.

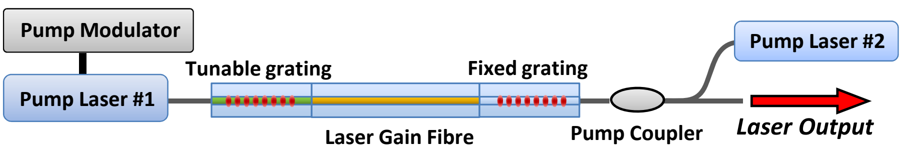

Fig. 1 Layout of the Q-switched fibre laser cavity.

3. Apodized point-by-point fibre Bragg gratings

Due to the step-wise nature of the PbP inscription technique, common FBG apodization techniques used in phase-mask and holographic inscription methods are fundamentally not applicable. Additionally, apodization via control over the power of the individual femtosecond pulses would likely be problematic due to the highly nonlinear laser-material interaction. However, the femtosecond PbP inscription method provides us with highly-localized micro-void modifications; therefore we chose to control the coupling strength of our gratings by varying the overlap of the modification with the core mode. The simplest implementation of this technique is illustrated in Fig. 2, where a linear variation of position across the core maps onto the Gaussian profile of the core mode to produce a Gaussian apodization profile [2].

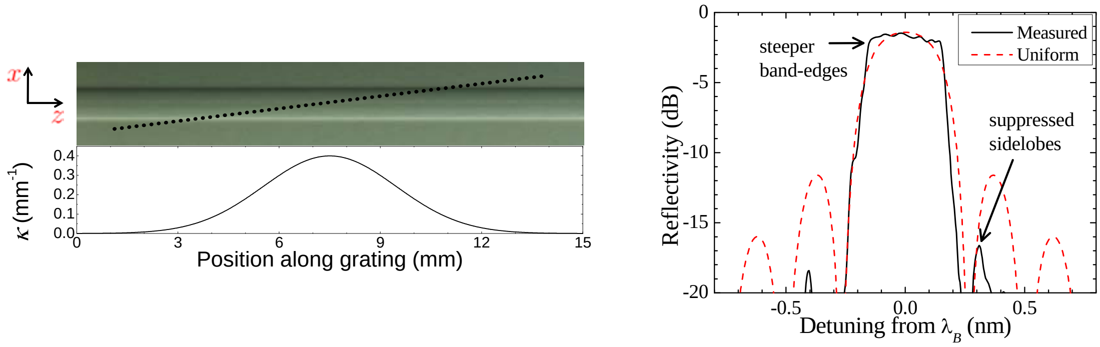

Fig. 2 (Left) Illustration of the Gaussian apodization technique. (Right) Reflection spectrum of a sinc-apodized FBG (black solid) compared to a simulation of a uniform FBG with equivalent strength and bandwidth (red dashed).

The ideal FBG reflectivity profile for the Q-switched laser would be a flat-top, which can approximately be achieved by a sinc apodization profile. In order to achieve such an apodization, π phase-shifts are required to achieve negative coupling amplitudes. We introduce discrete time-delays between the femtosecond pulses in order to achieve such phase-shifts, and combined with a tailored profile of the positions of the modifications in the core, we can achieve a sinc apodization profile [2]. Experimental results for a sinc-apodized PbP FBG are shown in Fig. 2. This grating exhibits steep band-edges, a relatively flat-top profile, and suppressed sidelobes; which should enable stable Q-switching at higher cavity pump powers and improved performance in the Q-switched laser.

4. Fibre laser performance with apodized PbP FBGs

The laser operates at a maximum repetition rate of 110 kHz, with pulses of <500 ns duration and average power of >70 mW. This constitutes an improvement in peak-power of approximately 200× compared to a previous embodiment using uniform PbP FBGs [4]. Output of the fibre laser at 90 kHz pulse repetition frequency is shown in Fig. 3.

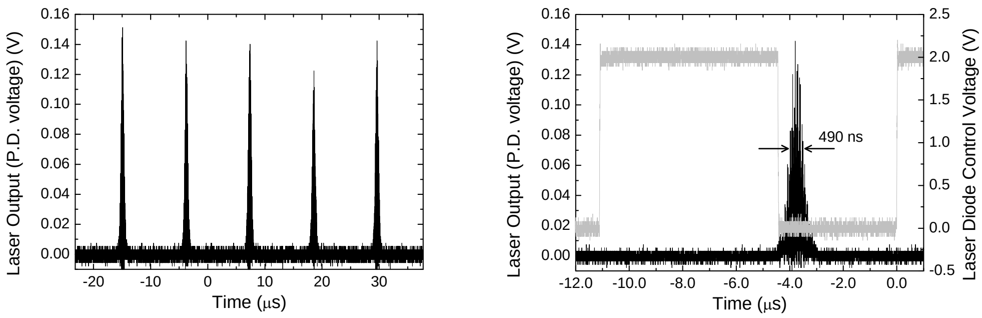

Fig. 3 Output pulses from the Q-switched fibre laser at 90 kHz. The diode control pulse for driving the Q-switch is shown in grey (right).

5. Conclusions

We have demonstrated the application of sinc-apodized PbP FBGs to an all-optical, actively Q-switched, all-fibre laser. Compared with a previous embodiment using uniform FBGs, the use of apodized gratings facilitated an improvement in pulse duration of an order of magnitude, and an improvement in pulse peak-power of approximately 200×. These results highlight that newly-demonstrated apodized PbP FBGs offer significant improvement over uniform FBGs and can provide significant benefit to fibre laser and sensing applications.

6. References

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