Packaging of an ultra-stable all-fiber-integrated NALM oscillator at 1 µm center wavelength for FEL facilities

Yi Hua[1], Henrik Tünnermann[1], Caterina Vidoli[1], Haydar Sarper Salman[1,2,3], Yuxuan Ma[1], Uwe Grosse-Wortmann[1], Lutz Winkelmann[1] and Ingmar Hartl[1]

1. *Deutsches Elektronen-Synchrotron DESY, Notkestrasse 85, Hamburg, 22603, Germany*
2. *Helmholtz-Institute Jena, Fröbelstieg 3, 07743 Jena, Germany*
3. *GSI Helmholtzzentrum für Schwerionenforschnung GmbH, Planckstrasse 1, 64291 Darmstadt, Germany*

In recent years, femtosecond fiber lasers mode-locked by nonlinear amplifying loop mirrors (NALM) [1] have shown many benefits for research and industrial applications such as high environmental stability, intrinsic low noise, and polarization-maintaining (PM) output. Previously we have demonstrated an all-fiber integrated, compact, and alignment-free NALM all PM Yb: fiber oscillator with sub-fs timing jitter [2]. Here we report on the next steps in packaging and engineering of this all-fiber compact oscillator. We developed a method to repeatably assemble lasers at a repetition rate required by DESY's FEL facilities.

All laser-oscillators at DESY's FEL facilities need to be synchronized with few-fs timing jitter to an integer divider of the accelerating RF field at 1.3 GHz. Since our oscillator is fully integrated and has no tuneable free-space optical components, it is a technical challenge to repeatably hit our target repetition rate of 1.3 GHz / 24 (54.167 MHz) within a few kHz. For this purpose, we developed the following method for cutting the intra-cavity fiber lengths such that the laser can be repeatably assembled to an overall cavity length within ~100 µm of the target: In the first step, we assemble a slightly long NALM oscillator cavity and measure the repetition frequency. Then, the laser is disconnected from its pump and connected to a low-coherence fiber reflectometer, a device which can determine a relative fiber length change with a resolution better than 60 µm. In the next step, we break the fiber loop by cleaving and measure the length difference between fiber-end B and a reference fiber (compare Fig 1a, left). The length of the fiber which needs to be cleaved off is then calculated and removed by a cleaver mounted on a micrometer resolution translation stage. The laser is then re-spliced. With this method, we achieve an accuracy of repeatability around ~100 µm, leading to the repetition rate accuracy of +/- 1.4 kHz for a 54.167 MHz laser cavity. The further coarse-tuning and repetition rate stabilization can be done by temperature control of the mounting plate for the intra-cavity fiber (10ppm length change or 0.5 kHz repetition rate change/ degree Celsius). Two piezo-actuators (slow and fast) are used for few-fs timing jitter synchronization.

Figure 1(b) shows the assembly of our all-fiber integrated NALM oscillator. Figure 1(c) shows the stabilization of the laser 24th harmonic of rep rate at 1.3GHz using only the resistive heater. As shown, a few kHz repetition rate change due to room temperature fluctuations can be easily compensated over long periods of time.

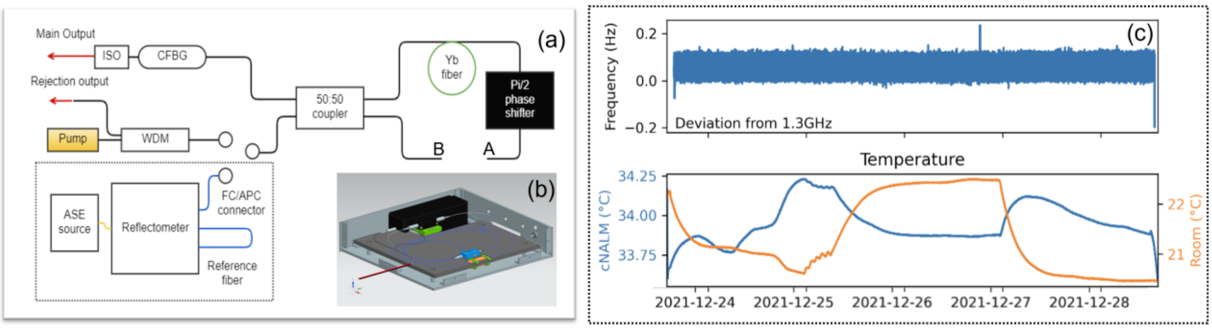

Fig. 1 (a) Setup configuration for precise fiber cutting; (b) oscillator electronic control box with the TEC plate for intra-cavity fiber; (c) Stabilization of 24th harmonic (1.3 GHz) of the oscillator rep rate by the TEC plate

In conclusion, we present the engineering and packaging of a compact all-fiber-integrated Yb: fiber oscillator with a precisely controlled repetition rate and without any tuneable free-space optical components. We developed a method to precisely cut the intracavity fiber lengths such that a target repetition rate can be reached repeatably within +/- 1.5 kHz. Further packaging and engineering steps, control system integration and long-term repetition rate stabilization with few fs timing jitter will be reported at the conference.

References

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[2] Y.Ma, et al. "Compact, all-PM fiber integrated and alignment-free ultrafast Yb: fiber NALM laser with sub-femtosecond timing jitter." Journal of Lightwave Technology 39.13 (2021): 4431-4438.

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