Broadly tunable quantum-dot based ultra-short pulse laser system with different diffraction grating orders

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A broadly tunable quantum-dot based ultra-short pulse master oscillator power amplifier with different diffraction grating orders is an external-cavity resonance feedback is studied. A broader tuning range, narrower optical spectra as well as higher peak power spectral density (maximum of 1.37 W/nm) from the second-order diffraction beam are achieved compared to those from the first-order diffraction beam in spite of slightly broader pulse duration from the second-order diffraction.

Introduction: High-power semiconductor ultra-short pulse laser systems with wide wavelength and/or broad pulse repetition rate tunability are very useful for nonlinear imaging techniques [1], especially in the biomedical field [2]. The wide tunability offered by the quantum-dot (QD) diode lasers, due to the temperature insensitivity, ultrafast carrier dynamics and broad gain bandwidth [3,4], is very promising for the development of broad tunable high-power picosecond source. Due to the merits of the diffraction grating as the external-cavity feedback, extremely broad wavelength tunability from a pulse laser could be achieved using diffraction grating techniques [5,6]. In this Letter, a tunable master oscillator power amplifier (MOPA) picosecond optical pulse source using all QD structures is investigated. The MOPA system consisted of a QD external-cavity passively modelocked laser (ECMLL) and a tilted QD semiconductor optical amplifier (SOA). A comparison between the first and second grating diffraction orders for this wavelength tunable QD-MOPA was further investigated. A broader tuning range, and narrower optical spectra can be obtained from the configuration with the second-order of grating diffraction. Peak power spectral density achieved with the second-order of grating diffraction is much higher (~2 to 3 times) than that from the first-order of grating diffraction under similar operation conditions. The narrowest pulse of ~14 ps and the better dynamic contrast of RF spectra were observed from the setup with the first-order of grating diffraction and the dynamic contrast of RF spectra from first-order grating diffraction.

The scheme of the experimental setup is shown in Fig. 1. The tunable MOPA setup consists of a master laser and an optical amplifier to boost the output power, where the master laser is a QD-ECMLL and the optical amplifier is a QD-SOA.

The detailed description of the scheme of the experimental setup and the MOPA system can be found in [4]. In brief, the two-sectional gain chip had a total length of 4 mm with an 800 µm-long absorber section placed near the front facet, and a ridge waveguide width of 6 µm with 7° tilting from the normal direction of the cleaved facet. Both facets of the gain chip had conventional antireflective (AR) coating, which resulted in total estimated reflectivities of ~10^-5 for the rear facet and ~10^-2 for the front facet. The active region of the gain chip consists of 10 non-identical InAs QD layers, similar to that described in [7]. The SOA had a length of 6 mm and a gain guided waveguide width changing from 14 µm at the input facet to 80 µm at the output facet. The tapered SOA was fabricated from the wafer with the same epitaxial structure as the gain chip. Both the gain chip and the SOA were kept at 20°C by Peltier coolers. The diffraction grating (DG) had a blaze wavelength of 1.25 µm and groove density of 600 grooves/mm. Broad wavelength tunability in the modelocked regime was achieved under a variety of bias conditions: gain chip current of 600–900 mA, reverse bias applied to the absorber section of the gain chip changing between 1 and 5 V, and SOA current of 2180 mA.

In Fig. 2, the tuning range from both cases can be increased by increasing the injection current of the gain chip. The maximum fundamental modelocking (FML) wavelength tuning range of nearly 100 nm (from 1187 to 1283 nm) has been achieved under 900 mA current applied to the gain chip with the second-order grating diffraction. In comparison, the maximum FML wavelength tuning range with a first-order grating diffraction is only 82 nm under similar operation conditions. For a higher injection current (e.g. 1 A) applied to the gain chip, we achieved a 118 nm tuning range (see Fig. 3) from the second-order grating diffraction. But the FML stability (from the RF linewidth and signal-to-noise ratio) under such a high current is not as good as that under a relatively low current because of a faster gain recovery [8]. The investigation is still in progress.

![Fig. 1 Configuration of tunable MOPA system and measurement setup, consisting of diffraction grating (DG); optical isolator (OI); half wave plate (HWP); singlemode fibre (SMF); fibre splitter (FS); optical spectrum analyser (OSA); autocorrelator (AC); oscilloscope (Osc); photodetector (PD); RF spectrum analyser (RFS)](image)

![Fig. 2 Tuning range limits for MOPA system operating in modelocking regime for different pump currents applied to gain chip and constant SOA current of 2180 mA for two configurations of external cavity: using first (red lines) and second (black lines) grating diffraction orders](image)

In theory, the output power from the configuration with a first-order of grating diffraction should be higher than that from the configuration with a second-order, whereas we did not find an obvious difference between the two configurations with the different DG orders. As shown in Fig. 4, the highest peak power was obtained from the MOPA with a second-order grating diffraction at 1226 nm. However, the peak power changes not too much with an increasing current applied to the gain chip because the pulse duration increases with increasing current and offsets the increase of average output power with increasing current.

![Fig. 3 Optical spectra of tunable gain chip in modelocked operation with gain chip current of 1 A, reverse bias of 0–4 V](image)

![Fig. 4 Dependence of MOPA output peak power on wavelength for first (red curve) and second (black curve) grating diffraction orders. Gain chip and SOA currents are 600 and 2185 mA, respectively](image)
For the second-order DG configuration, it can be treated as a stricter filter so that the optical spectra should be narrower than that for the first-order DG configuration. Correspondingly, the pulse duration from the setup with the first-order DG should be somewhat narrower than that from the setup with the second-order DG. As expected, we found a full-width at high maximum (FWHM) of the optical spectra from the setup with the second-order DG much narrower than that from the setup with the first-order DG within the whole tuning range from the experiments. On the other hand, the pulse durations from both cases are similar although a slightly broader pulse duration from the second-order diffraction can be observed. The narrowest pulse of \( \sim 14 \) ps was found from the setup with the first-order DG. The dynamic contrast of RF spectra from the first-order DG is better and each case has its own merits.

The peak power spectral density which describes how the peak power of a pulse is distributed with wavelength is very important for some applications [9]. From Fig. 5, we can see that the peak power spectral density obtained with the second-order DG is much higher than that from the first-order DG under the similar conditions, which can be attributed to the obvious difference of the FWHM of the optical spectra.

**Conclusion:** From comparison of the two configurations with different DG orders, the following conclusions can be obtained. The tuning range from both cases can be increased by increasing the injection current of the gain chip. However, a broader tuning range can be achieved from the configuration with the second-order DG. As a trade-off, the narrowest pulse (\( \sim 14 \) ps) and better dynamic contrast of RF Spectra can be found from the first-order DG. For consideration of potential applications, the peak power spectral density obtained with the second-order DG is much higher than that from the first-order DG under similar conditions, which suggests that the second-order DG is more promising.

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**References**


