Intensity fluctuation reduction in multi-wavelength visible sub-nanosecond optical pulses based on the pulsed operation of semiconductor-laser optical amplifier

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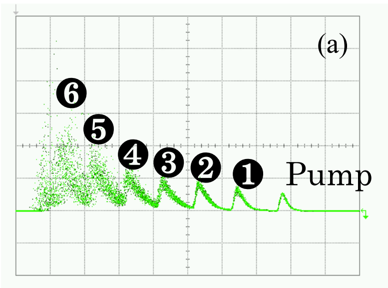
INTRODUCTION The pulsed-mode stimulated emission depletion (STED) microscopy is attracting much attention to realize efficient super-resolution bio-imaging [1]. In our previous report, we have demonstrated a sub-nanosecond multi-wavelength STED optical pulse source ranging from 546-nm to 620-nm based on gain-switched semiconductor optical amplifier (GS-SOA) method incorporating multistage amplification, second harmonic generation (SHG) and stimulated Raman scattering (SRS) [2]. The developed method successfully produced multi-wavelength optical pulses having a maximal peak power of 20-W, which value is nearly two orders of magnitude higher than that for optical pulses directly generated from a commercially -available red laser diode (LD) [3,4]. However, in the previous experimental work, we have observed quite large intensity fluctuations in the SRS optical pulse temporal waveforms. Since we are using multi-stage nonlinear wavelength conversion process to obtain higher-order SRS optical pulses, it is reasonable to consider that the origin of the above fluctuations is the intensity fluctuation in fundamental excitation optical pulses. In the present report, we indicate that this understanding is correct, based on an experimental study.

EXPERIMENT and RESULT To reduce the intensity fluctuations in the fundamental 1064-nm optical pulses, we just increased the CW light power injected into the SOA that is excited by electric pulses. This is because an amplifier, in general, can suppress intensity fluctuations when it is used in a strong gain-saturation condition. The CW laser power was chosen to be 3 mW in the previous experiment. In contrast, the CW laser power was increased to 10 mW in the present experiment; as a result, we confirmed on the oscilloscope that the intensity fluctuation noise for 1064nm sub-nanosecond optical pulses was drastically improved. This situation was also true for SHG converted sub-nanosecond optical pulses. Furthermore, we also observed a notable reduction in the intensity fluctuation noises in higher order SRS pulses that are generated in a 100-m long single-mode optical fiber (Fujikura, SM63-PS-U40D) through injection of 532-nm SHG optical pulses, which have 300-nJ pulse energy and 370-ps pulse width before coupled. The resultant SRS pulses' oscilloscope traces are shown in Fig. 1; (a) indicates the SRS pulses generated with 3-mW CW laser power, while (b) is with 10-mW laser CW power. It is obvious that the intensity fluctuations are reduced especially in the higher SRS pulse waveforms. The present results show that further improvements in the fundamental-laser-pulse intensity-fluctuation-noise feature will be beneficial for the realization of a practical-use multi-wavelength STED optical pulse light source employing the SRS process.



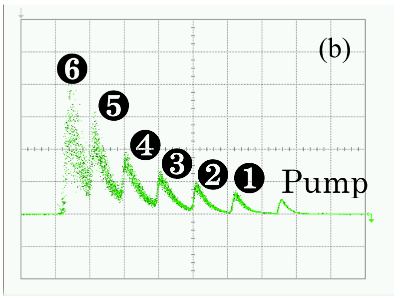


Fig.1 (a) SRS pulse waveforms generated with 3-mW CW laser light power incidence into the SOA. (b) SRS pulse waveforms for 10-mW CW laser light power incidence. In (a) and (b), the pump and the SRS pulses are labeled by Pump and SRS order numbers 1 to 6. The temporal separation of the pump pulse and the SRS pulses is due to the dispersion accumulated in the 100-m long single mode fiber.

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