Introduction and motivation

The wavelength of laser radiation is usually constant and changing it is extremely hard, which is why in practice, parametric light generators are used, which allow to continuously change radiation wavelength in a wide spectral range. Currently, the parametric generators are created with ultrashort (less than 100 ps) and long (more than 1 ns) pulse durations, however subnanosecond pulse (less than 1 ns and more than 100 ps) generators have not yet been invented. This is due to certain physical limitations — in the case of subnanosecond pulses, the damage threshold of many nonlinear media is lower than the parametric generation threshold [1–3].

The goal of this research was to construct and investigate of BBO subnanosecond optical parametric amplifier (OPA).

Experiment and methods

The optical setup for the measurements is depicted in Fig.1. In the experiment an Nd:YAG microchip system with an amplification stage — MOPA and harmonic modules was used. The microchip generated three wavelengths (1H – 1064 nm (100 μJ), 2H – 532 nm (40 μJ), and 3H – 355 nm (90 μJ)) at a pulse frequency of 1 kHz with a pulse duration of 600 ± 15 ps. The radiation from the first harmonic emitted by the laser was separated from the second harmonic by a beam splitter and used as a seed source for the supercontinuum generation. The 1H radiation with the use of mirrors was directed to a lens that focused the radiation into 1 m photonic crystal fiber. The radiation emitted from the fiber was collimated and directed to the BBO crystal. To achieve OPA, the pump and seed radiation must coincide in time and space, so a delay line of 3H was used, which allowed a corresponding delay in the pump radiation. After the delay line, 3H radiation was directed to the BBO crystal. BBO crystal (6 mm x 9 mm x 15 mm) was cut at θ = 28.2° and φ = 90° for type I phase synchronism.

Results

In the study, generated continuum radiation is seed for parametric amplification of the longer wavelength (idler) wave (maximum power was 5.7 mW) and 3H was an pump wave (355 nm) with a maximum power of 23 mW. The difference frequency wave generated in the process has shorter wavelength than the seed radiation, thus we call it the signal wave.

The first measurements were made by measuring the dependence of the supercontinuum spectrum on the pump power in the visible and infrared spectra (Fig. 2). Laser induced damage threshold (LIDT) of the PCF material (fused silica) limited maximum pump power that we could use for continuum generation (15 mW). Supercontinuum spectrum propagated from 720 nm to 1600 nm at maximum pump pulse energy. The change in the spectrum begins at the pump and then, due to nonlinear phenomena, slowly spreads to both the visible and infrared regions of the spectrum. We also see that the spectral intensities for the individual components of the spectrum are similar.

We measured the signal wave spectra with different BBO crystal angles (tuning range from 28.7° to 31.3°) which are shown in Fig. 3. The range of the signal wave spectrum was obtained from the range of 470 nm to 660 nm. After measuring the signal wave spectra, the idler wave spectra were also measured. The idler wave spectral range was obtained from 765 nm to 1450 nm.

In the study, we measured the signal wave power from the seed power at different signal wavelengths (Fig. 4). The maximum signal wavelength was 84 μJ at 532 nm. Pump to signal conversion efficiency is very low and does not exceed 0.35% for any wavelength, which is due to low spectral power density of the seed radiation, low pump intensity and relatively large spatial walk-off effect in the BBO crystal. Moreover, strong spatial walk-off effect between pump and signal/idler waves in the BBO crystal also limited parametric amplification efficiency. The dependence of the signal wave power on the pump wave power was studied in the work (Fig. 6). Seed power was adjusted by changing seed pump power, which also considerably changed spectral characteristics of the seed radiation. Results for most wavelengths are very similar to signal wave maximum power dependence on pump power pulse.

We also measured BBO OPA signal pulse duration at various wavelengths (Fig. 6.) Generated signal pulses have subnanosecond durations ranging from 166 ps to 303 ps. Longer generated pulse duration correlates with greater maximum output power indicating that stronger nonlinear interaction yields signal pulse duration closer to the pump pulse (500 ps) duration.

We also have performed the numerical simulations (Fig. 7.). The numerically calculated pulse profiles qualitatively agree with the experiment — signal pulses were in the subnanosecond range.

Conclusions

We have achieved subnanosecond optical parametric amplifier in beta barium borate (BBO) crystal. Signal wavelength tuning in the 470 nm – 660 nm spectral range was achieved and was limited by seed radiation spectral extent. Maximum output power of the OPA is limited by laser induced damage in the BBO crystal by the pump radiation and seed radiation spectral power density. Pulse duration measurements generated pulses also have subnanosecond durations ranging from 166 ps to 303 ps at different signal wavelengths.

The results of this work will be used for further development of more effective subnanosecond OPA systems. This research is founded by the European Regional Development Fund according to the supported activity ‘Research Projects Implemented by World-class Research Groups’ under Measure No. 01.2.2–LMT–K–718. Grant No. 01.2.2–LMT–K–718–03–0004.

References


Fig. 1: Experimental setup of measurement system: L – lens; BS – beam splitter; Br. Pol. – Bragg polarizer; M1 – half-wave phase plate; M1 – j = 1064 nm mirrors (AOI = 45°); M2 – j = 351 – 361 nm mirrors (AOI = 47°); M3 – j = 351 – 361 nm mirrors (AOI = 49°); M4 – Aluminium mirror with Ag protection; PCF – photonic crystal fiber; R – retroreflector; OB – microscope objective; BBO – beta barium borate crystal.