University of Hamburg, Department of Physics

Nonlinear Optics

Kärtner/Mücke, WiSe 2019/2020

Problem Set 5

Issued: 22.11.2019 Due : 29.11.2019

Tunable radiation in the visible and ultra-violet spectral region

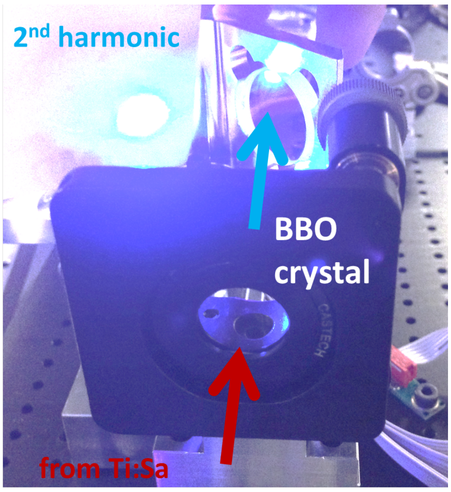

Figure 1: Frequency doubling of a Ti:Sapphire laser beam in a BBO crystal.

Modern solid-state lasers allow for the generation of a vast variety of different wavelengths. For example, Ti:Sapphire lasers can provide tunable radiation in the the spectral region of 700 - 1000 nm. With modern mode-locking techniques, these lasers generate pulses with pulse durations shorter than 30 fs and up to 2 W average power at pulse repetition rates of 100 MHz. The corresponding peak intensities can reach 0.6 MW. These high powers enable the generation of ultra-short pulses in the rage from 350 nm to 500 nm via frequency doubling. Here, you should design the frequency doubling stage for an ultra-short laser pulse from a Ti:Sapphire laser. Ultra-short pulsed lasers in the visible and UV are important for studying photobiological processes and performing semiconductor spectroscopy (e.g. on GaN) as well as pump sources for broadband OPA (optical parametric amplifiers) in the visible spectrum that can yield even broader spectra and shorter pulses. In the following we want to concentrate on β-Barium-Borat (BBO) as a crystal for our frequency doubling process.

BBO is a negative uniaxial crystal with refractive indices given by the Sellmeier's equations:

$$n_o^2 = 2.7359 + \frac{0.01878}{\lambda^2 - 0.01822} - 0.01354\lambda^2 \tag{1}$$

$$n_e^2 = 2.3753 + \frac{0.01224}{\lambda^2 - 0.01667} - 0.01516\lambda^2 \tag{2}$$

With λ inserted in units of micron.

1. Your goal is to phase match the entire Ti:Sa spectrum to its second harmonic completely (ranging from the long pump wavelengths down to the short ones). Which phase matching technique would you implement for frequency doubling if you want to phase match wavelengths as short as possible? Argue, whether you would rather prefer type-I or type-II phase matching! Which beam would be the ordinary and which one the extraordinary beam and how would you choose your crystal orientation?

2. Compute the phase matching angle Θ for frequency doubling of waves in the range 700-1000 nm! Plot the phase matching angle as a function of wavelength $\Theta(\lambda)$!

3. Choose the crystal orientation in a way that the effective nonlinear optical coefficient d_{eff} is maximized! Plot d_{eff} as a function of wavelength of the doubled light! Use that d_{11} is much larger than all other elements of the nonlinear coefficient tensor.

4. Compute an expression for the "walk-off "-angle as a function of wavelength of the doubled light, assuming type-I phase matching.

5. Derive an expression for the bandwidth of the frequency doubling. Plot the bandwidth in units [bandwidth · crystal length] as a function of the wavelength of the input light.

6. Now we want to frequency-double 30 fs, 800 nm sech-shaped pulses. Derive an expression for the upper limit of the length of the nonlinear crystal!
(Hint: for a given pulse duration, there is a minimal possible bandwidth, i.e the Fourier limited bandwidth.)