Modifications of nonlinear optical properties inside crystals with ultrafast laser pulses

Nonlinear optics is field of science which studies intensity-dependent interaction between light and matter. One of the most profound nonlinear optical effects are parametric light conversions, with a second harmonic generation as an example. These effects allow to change colour of laser light (its wavelength) and second harmonic generation allows to create one new photon of high energy (e.g. blue) from pair of two photons of half of the energy (red). Another example of nonlinear processes is multiphoton absorption, the process where at low light intensities the material is transparent and only light of high intensity is absorbed. This effect can appear when the light intensity is high enough that probability of simultaneous absorption of multiple photons becomes significant.

Laser light is broadly use in bio-medical, homeland security, consumer electronics and many other sectors of industry. All these applications require light of appropriate wavelength, and this need of laser light at different, sometimes very specific, wavelengths stimulates development of photonics and nonlinear optics since the invention of the laser by Theodore H. Maiman in 1960.It is not possible to simply make lasers emitting in any necessary spectral ranges, but the nonlinear optical effects can convert coherent light of one (fundamental) wavelength into another and cover wide spectral rage from deep-ultraviolet through visible, infrared up to terahertz radiation.

Efficient light conversion by parametric processes requires fulfilment of few parameters. First, it requires material which possesses nonlinear optical properties, in terms of second harmonic generation it is a quadratic second order nonlinear susceptibility. Second, because nonlinear susceptibilities are extremely small, the incoming light intensity must be high enough that any visible effect can appear. The last but not least is that the velocities of fundamental and generated waves must be equal. Speed of light in vacuum, commonly denoted c, does not depend on colour of light, but in medias, such as glasses or crystals, speed of light is slower than in vacuum and depends on its colour, this effect is called dispersion. It means that the fundamental and generated, e.g. second harmonic, waves will propagate with different velocities and there will be a phase mismatch between them. This phase mismatch is in fact the strongest limiting factor in applications of parametric processes for light conversion.

Femtosecond laser writing allows to very locally modify properties of material via multiphoton absorption. Light tightly focused inside the material will be absorbed only in its focus, where its intensity is orders of magnitude higher than elsewhere. In this way it is possible to change material properties in 3D fashion. This method has been already successfully used for production of integrated optical circuits and, with post processing using etching agents, for production of microfluidic channels in glasses.

The project objective is to study modification of nonlinear properties in ferroelectric, semiconductor, organic and inorganic crystals, induced by tightly focused ultrafast laser pulses. In all these four groups of crystals it is possible to find materials with very high nonlinear coefficients, but only in ferroelectrics it is relatively easy to produce periodic structures allowing phase matching, but only in two dimensions. For semiconductors, creation of periodic structure is extremely complicated and even small samples have price tags of tens of thousands of dollars, and for organic and inorganic crystals such a method basically does not exist. Successful results of this project will benefits towards creation of three dimensional nonlinear photonic structures allowing for phase matching and efficient nonlinear light conversion in crystals, in which it is not possible otherwise.

Within this project, I will start a new research team *FemtoScribe*, which scientific effort will contribute towards the understanding of ultrafast light-matter interaction and light induced structural changes in ferroelectric, semiconductor, organic and inorganic crystals. This research will push forward the frontiers of knowledge about ultrafast light-matter interaction inside crystals and expose Polish scientist to cutting-edge technologies. Developing method of all-optical engineering of nonlinear properties of crystalline materials will allow to obtain state-of-the-art photonic devises for integrated nonlinear photonics circuits, nonlinear parametric light conversion and, potentially, a generation of terahertz radiation.