Problem Set 1 – Phys 7650 – Nonlinear Optics – Spring 2015

Due date: Th 5 February

1. This problem shall give you a feeling for intensities, energies, and frequencies of light in the visible and infrared. Consider two cw laser sources, (1) a green, e.g., HeNe laser ($\lambda = 543$ nm), and (2) an IR, e.g., CO_2 laser ($\lambda \sim 10\mu$m), both with a power of 0.1 mW each.

   a) Assume you focus the light using appropriate optics down to a spot size of 10μm diameter. What is the irradiance/intensity [W/cm^2]? What is the electric field strength [V/m]?

   b) Discuss how intensity and field strength compares if instead of the laser you were to use a 100 W light bulb converting say 2% of its electric power into light. Distribute the radiation evenly over a solid angle $\Omega = 1$ sterad by a reflector. Calculate the light intensity and electric field of the light focused again to a spot size of 10μm diameter.

   c) Now we use a pulsed laser, $\lambda = 800$ nm, pulse duration $\tau = 100$ fs, repetition rate $f = 80$ MHz, average power $P = 0.1$ mW as above. Calculate the energy per pulse; the peak power, i.e., the power during the pulse; the intensity in a 10μm diameter focus and the peak electric field strength therein.

2. We talked about the challenges with the MKS vs. Gaussian units which are amplified in nonlinear optics. Familiarize yourself with the units of the nonlinear susceptibilities in both systems. Then assume $\chi^{(2)} = 1 \times 10^7$ esu for a given material. What is the corresponding value in MKS units considering the convention $P^2 = \epsilon_0 \chi^{(2)} E^2$.

3. *Phase matched SHG*: β-barium-borate (β-BaB_2O_2, BBO) is a commonly used nonlinear optical material. A typical task you may face is to frequency double a laser beam.

   Go to the course website: http://nano-optics.colorado.edu/index.php?id=64 to download a data sheet for BBO. Familiarize yourself with the data provided. Then calculate and plot the graph describing the crystal orientation (phase matched angle) versus laser wavelength for type-I and type-II phase matched SHG.

4. *Power conversion efficiency*: We have derived the expression to describe the intensity for phase matched SHG as a function of nonlinear optical crystal and laser parameter in the infinite plane wave approximation. This expression is also approximately valid for a Gaussian input beam. Consider SHG in BBO cut for phase matching with a length of 5 mm and effective nonlinear susceptibility of $\chi^{(2)} = 4.14$ pm/V. If the fundamental laser pulses have 10 nJ pulse energy, 100 fs duration, and a Gaussian beam profile with diameter of 0.2 mm, what is the energy conversion efficiency.

5. *Numerical solution to the nonlinear wave equation*: The nonlinear wave equation can be solved numerically without making any of the assumptions we made it class. Try to solve for the second-harmonic intensity as a function of crystal thickness under phase-matched or non-phase matched conditions using, e.g., BBO and for a plane wave excitation and compare with the result using the common approximations.