Quasi-Phase Matching of Soft X-ray Light from High-Order Harmonic Generation using Waveguide Structures

by

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Thesis directed by Profs. Henry C. Kapteyn and Margaret M. Murnane

Ultrafast laser technology has made it possible to achieve extremely high field intensities, above 10^{18} W/cm^2, or alternatively, light pulses with extremely short time durations corresponding to only a few femtoseconds (10^{-15} s). In this high intensity regime, the laser field energy is comparable to the binding energy of an electron to an atom. One result of this highly non-perturbative atom-light interaction is the process of high-order harmonic generation (HHG). In HHG, the strong laser field first ionizes the atom. The subsequent motion of the free electron is controlled by the oscillating laser field, and the electron can reach kinetic energies many times that of the original binding energy to the atom. The high energy electron can then recollide with its parent ion, releasing a high energy photon. This process occurs for many atoms driven coherently by the same laser field, resulting in a coherent, laser-like beam of ultrafast light spanning the ultraviolet to soft X-ray regions of the spectrum.

In this thesis, I will present two major breakthroughs in the field of high harmonic generation. First, I will discuss work on quasi-phase matching of high harmonic generation, which has allowed increased conversion efficiency of high harmonic light up to the water window region of the soft X-ray spectrum ($\sim$ 300 eV) for the first time.[31] This spectral region is significant because at these photon energies, water is transparent while carbon strongly absorbs, making it a useful light source for very high resolution contrast microscopy on biological samples. Since the resolution is on order of the wavelength of the light ($\sim$ 4 nm for 300 eV), detailed structures of cells and DNA can be viewed. A table-top source of light in the water window soft X-ray region would greatly benefit biological and medical research. Second, I will present work on the generation of very high harmonic orders from ions. This work is the first to show that harmonic emission from ions is of comparable efficiency to emission from neutral atoms thereby

showing that high harmonic emission is not limited by the saturation intensity, or the intensity at which the medium is fully ionized, but can extend to much higher photon energies.[30] Both results were obtained by using a waveguide geometry for HHG, allowing manipulation of the phase matching conditions and reducing the detrimental effects of ionization. The ideas from this work are expected to increase the number of applications of high harmonic generation as a light source by increasing the efficiency of the process and opening up the possibility of generating multi-keV photon energies.

Dedication

To my parents.

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