Electric and Magnetic Field Measurements using Doppler-Free Saturation Spectroscopy

E. H. Martin
Fusion Energy Division, Oak Ridge National Laboratory, Oak Ridge TN 37830

Electric (**E**) and magnetic (**B**) field vectors are fundamental variables in the equations governing plasma physics – specifically – the Boltzmann and Maxwell equations. For this reason, a direct measurement of these vectors can provide a powerful diagnostic for the investigation of plasma and fusion science. In this presentation, an overview of a laser-based technique capable of locally measuring electric and magnetic field vectors will be discussed. The spectroscopic setup and quantum mechanical modeling required to obtain Gauss and V/cm scale resolution will be presented. Finally, the technique's capability will be demonstrated by presenting experimentally measured He I 2^1P to 5^1D spectra experiencing a magnetic field ranging from 600 to 900 Gauss.

Spectroscopy is a common technique used to measure magnetic and electric field vectors through the splitting of the spectral line profile. These phenomena are known as the Zeeman and Stark effect, respectively. Passive measurements based on observing spontaneous emission from excited states have been quite successful for large amplitude fields (|**B**|>5000 Gauss and |**E**|>1000 V/cm). However, to measure small amplitude fields active methods must be employed to reduce and/or eliminate spectral broadening mechanisms. The measurement of small amplitude fields is of significant importance for the heating, equilibrium, and stability of plasmas. Doppler-free saturation spectroscopy (DFSS) is an active laser-based technique capable of such measurements. This is possible because DFSS measured spectra can have a resolution that approaches the Heisenberg uncertainty principle, yielding access to the complete quantum structure of the electron.

DFSS is based on exciting electronic transitions using a tunable laser source. The spectrum is obtained by measuring the absorbed laser power as the laser frequency is swept over the transitions of interest. To obtain the Doppler-free resolution, the laser beam is split (90/10) into two separate beams referred to as the pump and probe. The beams are aligned such that they are counterpropagating at a small angle and overlap over at the desired measurement location. The counterpropagating geometry allows the detection of excitation events that occur in atoms having a velocity vector perpendicular to both beams. The result is an effective reduction in the Doppler broadening. In general, precise quantum mechanical and atomic physics modeling is required to extract the electric and/or magnetic field vector from DFSS measured spectra with Gauss and V/cm resolution. This stipulation is due to the complex behavior of the quantum states, optical pumping, and the crossover resonance.

DFSS has been successfully implemented in the Laser Spectroscopy and Quantum Sensing Laboratory (LsQsL) at ORNL to measure helium and hydrogen spectra with a x1000 reduction in the Doppler broadening. These measurements were conducted in a magnetized plasma source capable of operating in the range of |**B**|=600 to 900 Gauss. In this presentation, DFSS measured π and σ polarized He I 2^1P to 5^1D spectra experiencing Zeeman splitting due to a magnetic field ranging from 600 to 900 Gauss will be presented. The results obtained from fitting the spectra to the Schrodinger equation accounting for optical pumping and crossover resonance effects will be discussed, highlighting the impressive capability of laser-based spectroscopy.