Christopher Galea
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Towards Xenon Neutral Density Measurements Using Radar REMPI

Radar REMPI is a microwave-scattering-based resonance-enhanced multiphoton ionization diagnostic technique [1] which has been applied to detect trace species in air [2], measure electron loss rates [3], and measure temperature in gas mixtures and flames [4]. The resonance enhanced technique provides high selectivity in measuring species of interest, and hence can be used to measure the density of a neutral species in plasma (in Hall thrusters, for instance) and can also be used for remote magnetometry [5]. The diagnostic technique has a measurement time on the order of tens of nanoseconds and a sample volume length scale of less than 1 mm, allowing time- and space- resolved measurements.

Radar REMPI consists of two parts: first, resonance enhanced multiphoton ionization (REMPI) by a focused laser pulse to selectively ionize a species of interest, and second, coherent microwave scattering (Radar) by the small REMPI-generated plasma from an incident microwave beam. The scattered signal is directly proportional to the number of neutral atoms sampled. Figure 1(a) gives an illustration of the Radar REMPI process using a bistatic configuration (one transmitting horn and one receiving horn). The schematic of the monostatic configuration we use is shown in Figure 1(b), which is described in [2]. We utilize the two-photon resonance excitation of xenon at 256 nm with a one-photon ionization from this excited state, referred to as 2+1 REMPI. Since the laser is tuned to the two-photon resonance of xenon, we can selectively ionize low concentrations of xenon in various buffer gases. We are currently applying this technique in xenon-helium mixtures, where helium is the buffer gas, and the concentration of xenon is 10 ppm or less, which allows us to examine low partial pressures of xenon without the need of a vacuum pump.

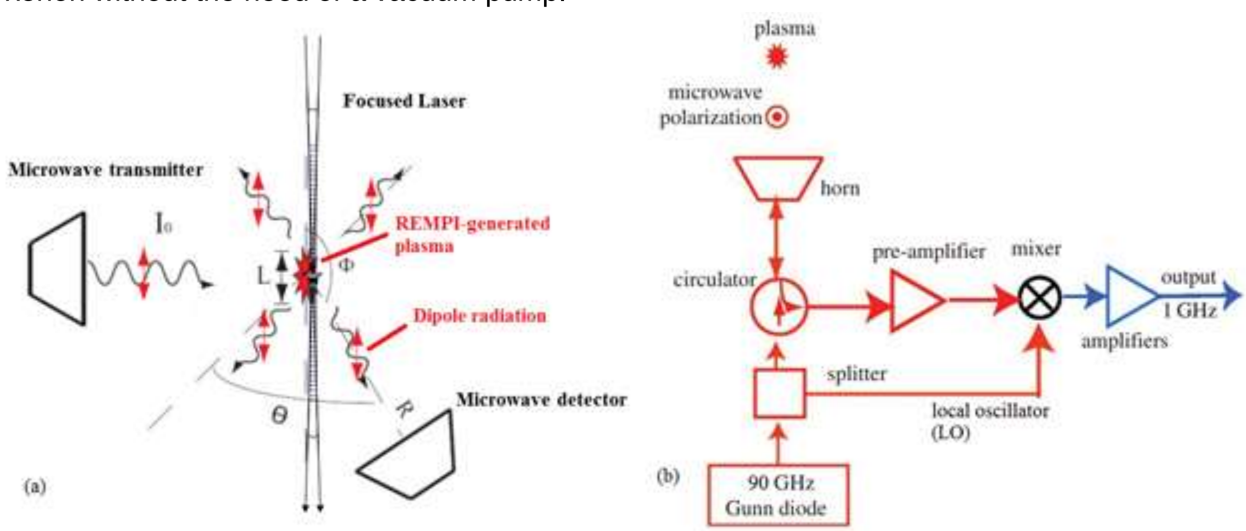

Figure 1: Illustration of the Radar REMPI process. A focused laser beam selectively ionizes xenon to create a small plasma (REMPI) which coherently scatters the microwaves from the

transmitter (Radar). (b) Experiment schematic (adapted from [2]) of the Radar REMPI homodyne system. Note the transmitter and detector are, in our case, one horn with a circulator.

A 0-dimensional kinetic model has been developed to determine the effects of collision frequency on the signal amplitude and determine a quantitative mapping between the signal obtained and the xenon neutral density. The model includes xenon neutrals, ions, two-photon excited state atoms, dimer ions, helium neutrals, and electrons. Photo-recombination, three-body recombination with the electron as the third body, and dissociative recombination are the recombination processes considered. Collision rates include those for electron-neutral helium collisions and Coulomb (electron-xenon ion) collisions. Lastly, the excited state population is modeled using two-photon excitation and one-photon ionization cross sections, along with quenching binary collisions between the excited state and electrons. We calculate the cross-section for two-photon excitation from the ground state to the $6p[5/2]_2$ excited state of xenon using the matrix element method described in [6].

The preliminary experiment and model results are compared for 1ppm xenon in atmospheric pressure (~760 Torr) helium, shown in Figure 2, which are in good agreement. Included also in a "without REMPI" simulation, which assumes a delta-function ionization in time of the xenon atoms for full xenon ionization, and comparison with the "with REMPI" simulation indicates the xenon is near fully ionized. The model shows that electrons cool drastically over the first ~50 ns, which results in a substantial decrease in the electron-neutral helium collision frequency, and hence further augmentation of the signal. This indicates that the signal depends strongly on both xenon neutral density and collision frequency, which shows the need for a more robust model for quantitative measurements of xenon neutral density.

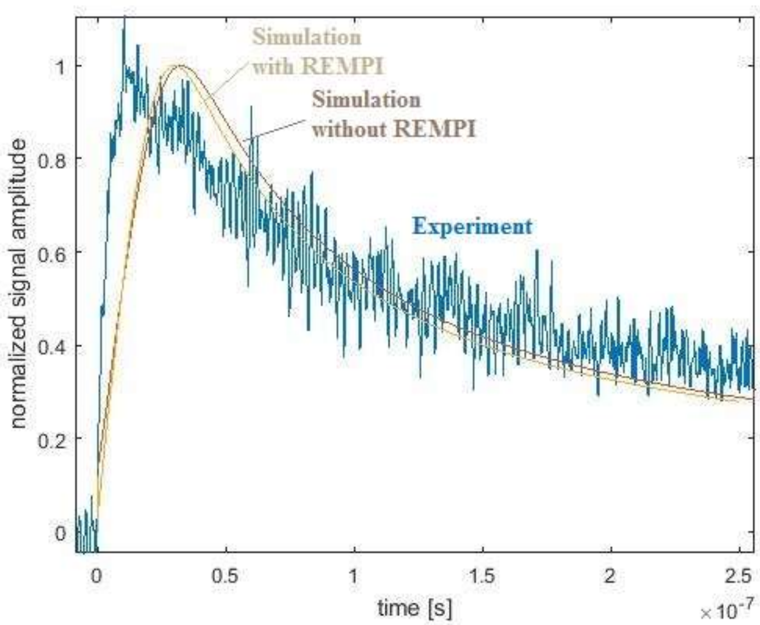

Figure 2: Comparison of 0-dimensional kinetic model with experiment results for 1ppm Xenon in atmospheric pressure (~760 Torr) Helium. The delayed peaks (relative to the laser pulse

duration of ~100 psec) are due to the electron-neutral collision frequency reaching a minimum as the electrons cool.

Work is currently underway to increase the sensitivity of Radar REMPI to obtain even lower density detection in gas mixtures, and then apply the technique to gas discharges at these lower densities to assess the diagnostic technique in an ionized gas. On the modeling and simulation end, we are incorporating relevant metastable states, as well as collisions and rates that are more prominent at lower pressures to develop a more robust model which can work under various operating regimes. After further refinement of the diagnostic technique sensitivity and modeling, we plan to apply this technique to measure xenon neutral density in the plume of a Hall thruster.

References:

[1] Zhang, Shneider, Miles, Phys. Rev. Letters 98, 265005 (2007)
[2] Dogariu, Miles, Applied Optics 50, A68-A73 (2011)
[3] Dogariu, Shneider, Miles, Applied Physics Letters 103, 224102 (2013)
[4] Miles et al., Phil. Trans. R. Soc. A 373 20140338 (2015)
[5] Dogariu, Chng, Miles, CLEO:2014, OSA (2014)
[6] Khambatta et al., Phys. Rev. A 39 3842 (1989)