SAND2015-8951C

DIRECT ELECTRON BEAM INJECTION EXPERIMENTS FOR TESTING AIR-CHEMISTRY MODELS

S.B. Swanekamp, D.D. Hinshelwood, J. Angus , A.S. Richardson, and D. Mosher*

Plasma Physics Division
Naval Research LaboratoryWashington
DC 20375

Keith Cartwright, Tim Pointon, and B.V. Oliver
Sandia National Laboratories
Albuquerque, NM

9/25/2015

Steve Swanekamp – presenter – 202-404-4361 – Steve.Swanekamp@nrl.navy.mil

Prefer oral

Unclassified

Abstract: Experiments to measure gas breakdown by direct electron-beam injection are being performed at the Naval Research Laboratory using a 100 kV, 10 kA, 50 ns pulser to provide data for air-chemistry modeling efforts.

*Independent consultant through Engility Corp., Chantilly, VA 20151

DIRECT ELECTRON BEAM INJECTION EXPERIMENTS FOR TESTING AIR-CHEMISTRY MODELS

S.B. Swanekamp, D.D. Hinshelwood, J. Angus, A.S. Richardson, and David Mosher*
Plasma Physics Division
Naval Research Laboratory
Washington, DC 20375

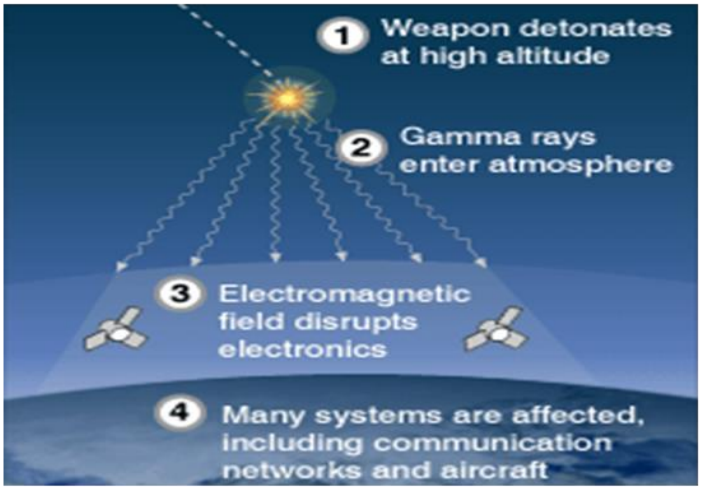
Keith Cartwright, Tim Pointon, and B.V. Oliver
Sandia National Laboratories
Albuquerque, NM

Abstract: Experiments to measure gas breakdown by direct electron-beam injection are being performed at the Naval Research Laboratory using a 100 kV, 10 kA, 50 ns pulser to provide data for air-chemistry modeling efforts.

Introduction

Both commercial and military assets are vulnerable to the electromagnetic pulse (EMP) created by photocurrents produced by the Compton scattering of the prompt-gamma rays in the atmosphere (see Fig. 1a). Through the photoelectric effect, x-rays can also produce photocurrents on the interior of satellites or reentry vehicles. If the magnitude of the induced current density is sufficiently large, these mission-critical components can be negatively affected by the large system-generated electromagnetic pulse (SGEMP) causing critical subsystems to fail. The short duration and large amplitude of the current density gives rise to a rapidly rising electric field which can cause electrical breakdown of the ambient gas inside. This electric field also drives a return current (see Fig. 1b) which partially neutralizes the beam current. The size of the electromagnetic pulse is determined by the magnitude of the net current. Therefore, gas chemistry is an important part of the SGEMP problem.

Because of the importance to understanding the overall EMP problem, there has been a continuing effort to develop better gas-breakdown models. The ambient pressure inside these components can range from vacuum to atmospheric pressure and these models fall into two pressure regimes. At high gas pressure ($p>>1$ Torr), the mean free path is very short compared to relevant spatial scales and the electron energy-relaxation time is short compared to any time-scales of interest. In this regime, a fluid model can be used in tandem with equilibrium transport coefficients (ionization rate, mobility, and energy-transfer frequency) precomputed and tabulated in a lookup table. The fluid equations are then used to compute the electron density (n_e), the fluid velocity (V_e), and the plasma energy (ε). These are then used to compute the plasma return current ($J_p=-en_eV_e$) which then feeds back into Ampere's law. At low gas pressure ($p<<1$ Torr), a fluid model is no longer valid. In recent years, a fully-kinetic model of gas breakdown called MCSwarm has been developed.[1] The MCSwarm model follows secondary electrons on a collision-by-collision basis so that it is accurate even when the energy relaxation rate is long compared to the time-scales of interest and collisions are non-local. The MCSwarm model has been coupled to the fully electromagnetic particle-in-cell (PIC) code Quicksilver[2] or Emphasis[3] to model EMP problems. This approach is computationally intensive but provides the most accurate model available for gas-breakdown for pressures below 1 Torr.



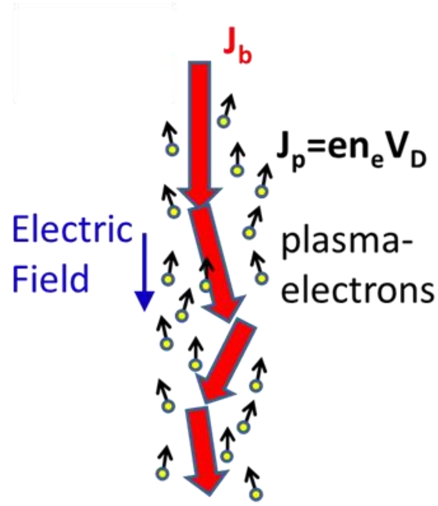


Figure 1. a) A nuclear event in space can produce a large number of detrimental electromagnetic pulse effects triggered by the interaction of a large x-ray flux with the environment. b) A rapidly rising beam current produced by the x-rays leads to the electrical breakdown of air and the production of plasma electrons and return current.

Efforts are underway to benchmark these codes using integrated tests on large x-ray facilities such the Z accelerator and NIF. While the system testing offered by these large x-ray facilities is necessary, the shot-rate and the experimental environment make fundamental measurements of critical plasma parameters difficult. In addition, the integrated tests include additional physics such as photo-electron production and x-ray-induced conductivity in the gas that further cloud the ability to benchmark gas-breakdown models. Many of these problems can be avoided by directly injecting a high-energy beam created by an external accelerator into the gas. Although these beams do not have the same energy and angular distribution as a beam created by the photo-emission process, the characteristics of the injected beam can be measured accurately and applied as initial conditions to code calculations. Direct electron injection also uses an accelerator that is much smaller, with a shot-rate that is orders of magnitude larger and is cheaper to operate than the large x-ray facilities.

Direct electron-injection experiments are being performed at the Naval Research Laboratory using a Febetron configured to provide a 100 kV, 10 kA, 50 ns electron beam pulse. A photograph of the Febetron accelerator is shown in Fig. 2. The beam is extracted from the accelerator through a thin, low-mass foil into a chamber filled with gases of various mixtures and different pressures. A variety of diagnostics can be fielded to provide modelers with critical benchmarking information. One critical parameter is the electron density. The line-integrated electron density is measured using a combination of optical and fiber-based interferometers. For electrical breakdown in air, plasma spectroscopy is used to measure light from excited states of molecular nitrogen (N_2) and mon-atomic nitrogen (N). These data can be used to determine the plasma temperature and also to infer when the assumptions of the MCSwarm model are no longer valid. In addition, the net current can be measured outside the beam path using b-dot loops. The total current measurements can be combined with a measurement of the injected beam current to provide a measurement of the plasma return current. The work presented here is a follow-on to previous work with a focus on pressures between 10 mTorr and 1 Torr where previous results showed large variability. Experimental and theoretical efforts will be conducted to understand this variability. A comparison of experimental data with code results should be valuable for code development. The available data and code results will be presented in this presentation.

Figure 2. A picture of the accelerator used for direct electron beam injection into gas experiments. The red line shows the HeNe laser used to obtain line-integrated electron measurements.

References:

[1]S.B. Swanekamp, D.D. Hinshelwood, P.F. Ottinger, J.W. Schumer, D. Mosher, M.L. Kiefer, D.B. Seidel, and T.D. Pointon, "A Monte-Carlo Code for Computing Transport Coefficients in Weakly Ionized Gas,". 2007 HEART Conference (San Diego, CA, March 2007).

[2] J. P. Quintenz, D. B. Seidel, M. L. Kiefer, T. D. Pointon, R. S. Coats, S. E. Rosenthal, T. A. Mehlhorn, M. P. Desjarlais, and N. A. Krall, "Simulation codes for light-ion diode modeling," Lasers and Particle Beams, vol. 12, pp. 283-324, 1994.

[3] EMPHASIS/Nevada UTDEM User Guide Version 2.0, C. David Turner, Michael F. Pasik, David B. Seidel, SAND2011-6644, 2011.