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Modified Paschen's law for Microscale and Nanoscale Gaps

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Abstract - Predicting gas breakdown is critical for applications requiring plasma formation, such as plasma assisted combustion and plasma medicine, and avoiding plasma formation, such as microelectromechanical systems (MEMS) and vacuum electronics. The continuing reduction in device size to nanoscale makes this characterization more important. Paschen's law, driven by Townsend avalanche, is well known in plasma physics. At microscale, the increased electric fields strip electrons from the cathode by field emission. These electrons ionize gas atoms near the cathode to create ions that enhance the surface electric field (and field emission current) and secondary emission. Instead of scaling with the product of pressure and gap distance, breakdown voltage scales with gap distance and continues to decrease at lower gap distances.

This seminar reviews theoretical and experimental efforts to characterize gas breakdown from microscale to nanoscale. Specifically, we will apply a matched asymptotic analysis to a theory unifying field emission and Paschen's law to derive analytic equations showing that the breakdown voltage scales linearly with gap distance when field emission drives breakdown. Furthermore, we will use these equations to assess the transition from the field emission regime to the classical Paschen's law and the implications on the well-known Paschen's minimum. We report experimental results showing that while surface roughness does not impact initial breakdown voltage, it dramatically alters breakdown voltage for subsequent breakdown events due to electrode cratering. We conclude by highlighting connections to other emission mechanisms and reporting progress on extending these simple theories to more realistic diode geometries.

Short Bio

Dr. Allen L. Garner received the B.S. degree (with high honors) in nuclear engineering from the University of Illinois, Urbana-Champaign, in 1996. He received an M.S.E. in nuclear engineering from the University of Michigan in 1997, an M.S. in electrical engineering from Old Dominion University in 2003, and a Ph.D. in nuclear engineering from the University of Michigan in 2006.

He was an active duty Naval officer from 1997 to 2003 and is currently a Captain in the Navy Reserves. From 2006 to 2012, he was an electromagnetic physicist at GE Global Research Center. He joined Purdue University in 2012, where he is currently an Associate Professor and Undergraduate Program Chair of Nuclear Engineering.

Prof. Garner received a University of Michigan Reagents' Fellowship and a National Defense Science and Engineering Graduate Fellowship. He has been awarded two Meritorious Service Medals, the Navy and Marine Corps Commendation Medal, and five Navy and Marine Corps Achievement Medal. He also received the 2016 IEEE NPSS Early Achievement Award.