Plasma Science and Technology Division
Room 315 - Session PS-ThA

Harnessing the Power of Plasmas for Real-World Applications: PSTD Award Lectures

Moderators: Sebastian Engelmann, IBM T. J. Watson Research Center, **Mingmei Wang**, Lam Research Corporation

2:20pm **PS-ThA-1** ***Time-Resolved Energy and Ion Energy Distributions during High-Powered Impulse Magnetron Sputtering (HIPIMS) with Cathode Voltage Reversal*** **, *David Ruzic*[1],** University of Illinois*; D. Barlaz, Z. Jeckell,* University of Illinois at Urbana-Champaign*; W. Huber, I. Haehnlein,* University of Illinois at Urbana-Champaign, Starfire Industries LLC*; T. Houlihan, B. Jurczyk,* Starfire Industries LLC **INVITED**

Reversing the potential on the cathode sputtering target immediately after the negative voltage pulse does remarkable things to the plasma, and if controlled correctly can make vastly superior thin films for a variety of applications.HIPIMS works by making a plasma dense enough to ionize the material being sputtered.Those target ions mostly return to the target and do self-sputtering.This leads to a very high current which is why the process is pulsed. Its advantages are that a small number of these ions do escape and go to the substrate, resulting in a higher ionization fraction.Its disadvantage is that fewer total atoms or ions reach the substrate resulting in a lower deposition rate.

Adding a positive voltage to the target changes everything.The plasma is expelled form the target region filling the device all the way up to the substrate being coated.This wave of plasma causes additional ionizations of the sputtered material, therefore increasing the ionization fraction reaching the substrate an increasing the deposition rate.The key though is that the plasma potential is raised by the exact voltage value of the positive pulse.This means that the ion energy reaching the substrate is controllable, without having to bias the substrate.In addition, by varying the time duration of the positive pulse with respect to the negative pulse, the ratio of target ions to working gas (Ar) ions can be controlled as well.

This talk will show detailed measurements of how this all occurs as a function of time including fast camera images.Several examples highlighting the applications made possible by such a system will be shown as well.

3:00pm **PS-ThA-3 PSTD Plasma Prize Award Talk: Plasma ON then OFF, ON - OFF, ON – OFF, ON - OFF: Who Knew Being Indecisive Could Work So Well!, *Lawrence Overzet*[2],** University of Texas at Dallas **INVITED**

The reasons for modulating the power to a plasma can seem obvious at first. Shorter on time durations can enable one to operate at much higher instantaneous powers! One could potentially reach a power regime which is not sustainable for the same system in continuous wave (CW). In fact, one of the early papers on modulating the power to an RF plasma did so because the plasma system couldn't handle the CW heat load;[1] but then the researchers discovered something quite surprising! We tend to assume that the electron density grows as the power increases during the plasma turn-on in a somewhat "quasi-equilibrated" fashion. Further, most of us have assumed (at one point or another) that the plasma is just decaying toward zero during the off times. Slow neutral chemistry is occurring and some ion-molecule reactions too of course, but nothing all that particularly interesting or worthwhile. Even though all the above seems clear to a great majority of us, it turns out that it can be downright wrong. I've spent the greater portion of my career studying the kinetics and mechanics of how plasmas turn on and then off (and back on again) because I find those kinetics to be fascinating. (I also feel a need to state that making those measurements and models can be quite challenging!) I've found that the fashion in which energy is put into the plasma's electron population varies in time during the turn-on and turn-off. The chemical reactions can change in surprising fashions because of this and few things are as simple as one might expect. Particles confined by a CW plasma can suddenly be encouraged to leave, electron densities can increase as the power to the plasma decreases, fewer electrons can cause more reactions (and light) and plasma diagnostics can be enabled which otherwise might not even be imagined.

[1]R. Boswell and D. Henry, Appl. Phys. Lett. 47 (10) 1095-7 (1985).

3:40pm **PS-ThA-5 PSTD Young Investigator Award Talk: Next Generation "Birkeland-Eyde": From NH_3 to NO*, Floran Peeters*[3],** DIFFER, Netherlands **INVITED**

In 1905 industrial-scale production of nitric acid began in Notodden, Norway. This development came in response to a global shortage of nitrogen fertilizer, required to feed the world. Where for years nitrogen fertilizer was obtained by harvesting diminishing supplies of guano, several initiatives were undertaken to produce nitrogen fertilizer artificially. Scientists and engineers in the US and in Europe independently developed nitrogen fixation methods based on breaking the strong molecular nitrogen bond using electric arcs, forming NO as an intermediate chemical. Sustaining arc discharges continuously, a definite requirement for commercial exploitation, leads to electrode sputtering and thus a limited lifetime of the reactor. This problem was solved by Birkeland and Eyde by rotating the arcs in a magnetic field, leading to a 40 MW nitrogen fixation plant which remained operational until the 1920's.

Starting in the 1910's the use of electric arcs for the fixation of nitrogen was slowly overtaken by the more energy-efficient catalytic Haber-Bosch process, in which NH_3 is formed from atmospheric nitrogen and hydrogen from natural gas. This high temperature, high pressure process, while an engineering marvel in its own right, suffers from a major drawback when viewed through a modern lens: its heavy reliance on fossil fuels.

With the global aim of transforming the chemical industry to rely on sustainably generated electricity,interest in fixing atmospheric nitrogen using only electrical power has gained renewed interest. In this contribution, an analysis will be given of the existing nitrogen fixation production chains and the possibilities and benefits of replacing these with new, plasma-based methods. Using insights gained from over a century of scientific literature, recent experiments and models, strategies for improving plasma-based nitrogen fixation methods will also be discussed.

[1] **2020 AVS Gaede-Langmuir Awardee**

[2] **2021 PSTD Plasma Prize Winner**

[3] **2021 PSTD Young Investigator Awardee**

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