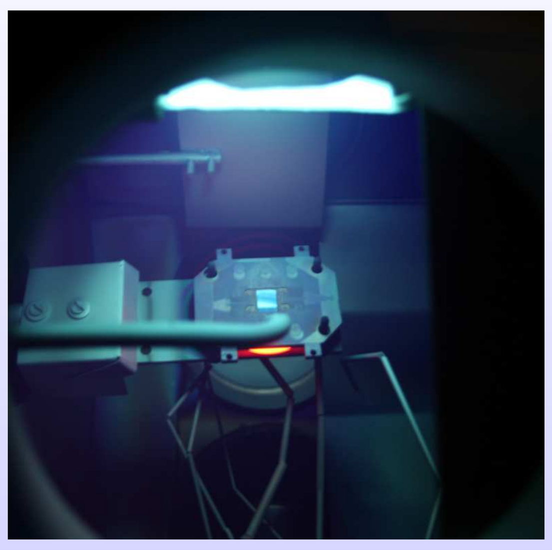
A global model study of a reactive high power impulse magnetron sputtering (HiPIMS) N_2/Ar discharge



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The global (volume averaged) model

- A global model (Gudmundsson, 2008) is applied to study a reactive high power impulse magnetron sputtering (HiPIMS) N_2/Ar discharge
- The discharge consists of (Thorsteinsson and Gudmundsson, 2009a,b):
  - Electrons, Maxwellian-like energy distribution (0.0259 – 10 V)
  - vibrational levels of the ground state nitrogen molecule $N_2(X^1\Sigma_g^+, v = 0-6)$ (0 – 1.68 eV)
  - metastable nitrogen molecule $N_2(A^3\Sigma_u^+)$ (6.17 eV)
  - nitrogen atoms $N(^4S)$, $N(^2D)$ (2.38 eV) and $N(^2P)$ (3.58 eV)
  - nitrogen ions N_2^+ (15.6 eV) and N^+ (14.5 eV)
  - argon atoms $Ar(3s^23p^6)$, Ar^m ($1s_5$ and $1s_3$) (11.6 eV), Ar^r ($1s_4$ and $1s_2$) (11.7 eV), excited argon atoms 4p states Ar(4p) (13.2 eV)
  - argon ions Ar^+ (15.8 eV)
  - titanium atom $Ti(a\,^3F)$ and titanium ion Ti^+ (6.83 eV)

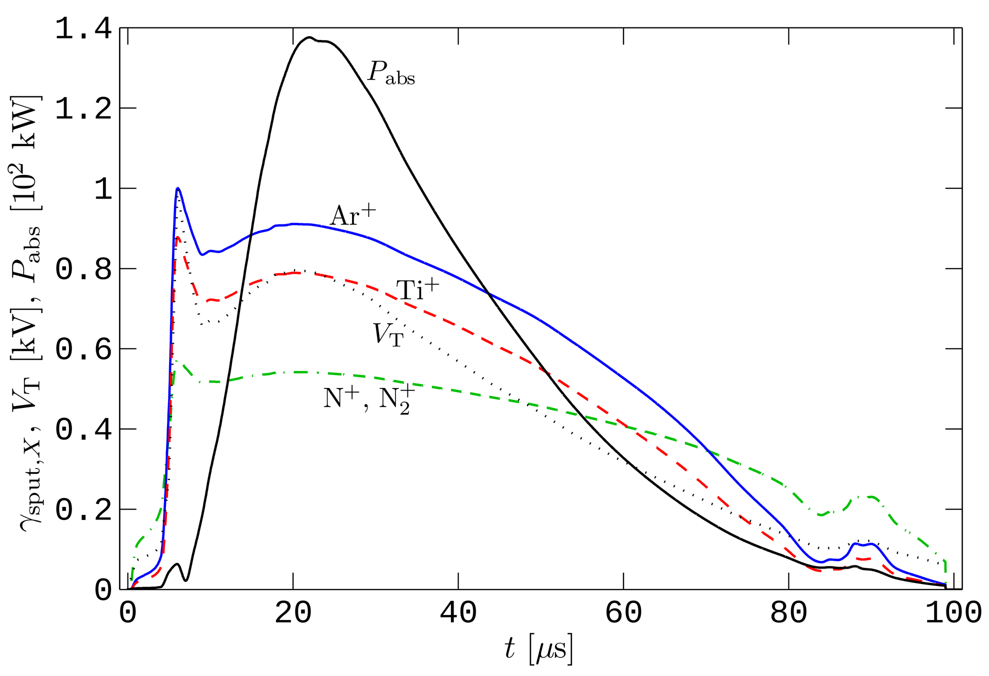

Figure 1: The temporal evolution of the sputtering yields $\gamma_{sput,X}$, the absorbed power P_{abs} and the target voltage V_T.

- Sputtering of metal atoms from the target by bombardment of positive ions with the rate coefficients

$$k_{sput,X} = u_B h_L \frac{R_T^2}{R^2 L}\gamma_{sput,X} \quad (1)$$

where $\gamma_{sput,X}$ is the sputtering yield for sputtering by positive ion X
- The sputtering yields are dependent on the ion energy, so the temporal evolution of the target voltage V_T must be known
- We use experimentally obtained current–voltage characteristics for the power P_{abs} and the target voltage V_T, that were measured for a pure Ar HiPIMS discharge (Gudmundsson et al., 2002)

Results and discussion

- The chamber is assumed to be made of stainless steel, cylindrical with R = 15 cm and L = 15 cm and the target is made of titanium of radius R_T = 15 cm
- The discharge pressure is 10 mTorr and the total gas flow is Q = 42 sccm which is 95% argon ($Q_{Ar} \simeq 40$ sccm, $Q_{N_2} \simeq 2$ sccm) and the gas temperature is assumed to be T_g = 430 K

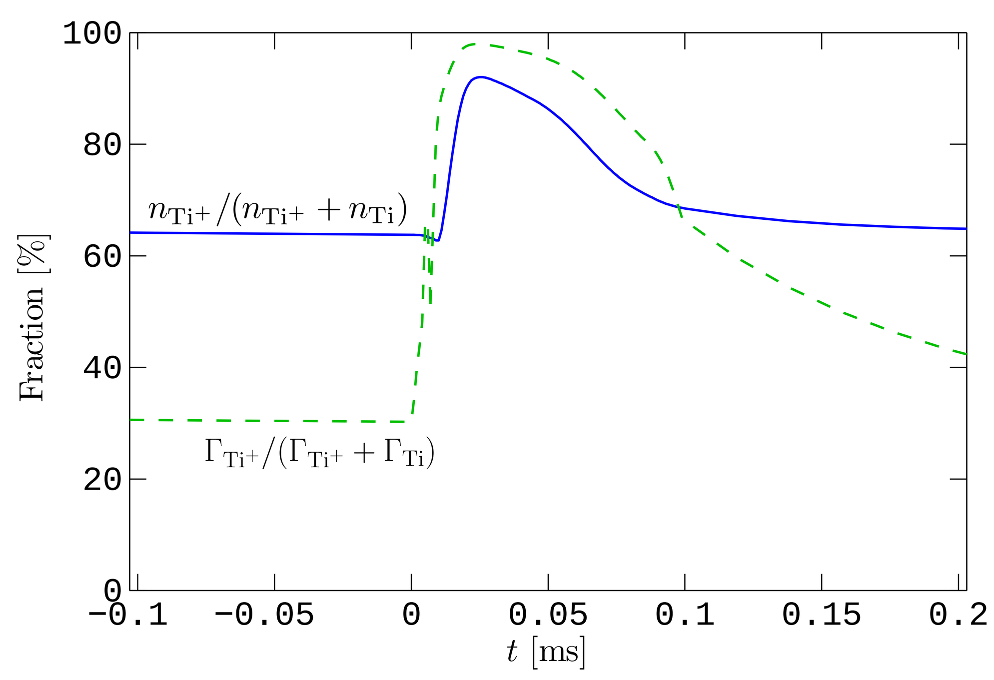

Figure 2: The temporal evolution of the ionized metal fraction $n_{Ti^+}/(n_{Ti^+} + n_{Ti})$ and the fraction of ionized metal flux at the substrate $\Gamma_{Ti^+}/(\Gamma_{Ti^+} + \Gamma_{Ti})$ at and around the tenth pulse period.

- The power is assumed to be deposited uniformly to a reduced volume V_p below the target that is cylindrical in shape and assumed to have the dimensions R_p = 15 cm and L_p = 7.5 cm
- The pulse length is roughly 100 μs (FWHM of about 32 μs) and the repetition frequency is 500 Hz (i.e. a period of T = 2 ms)
- The fraction of ionized metal flux at the substrate is significantly larger than the ionized metal fraction when the power is on but significantly smaller when it is off

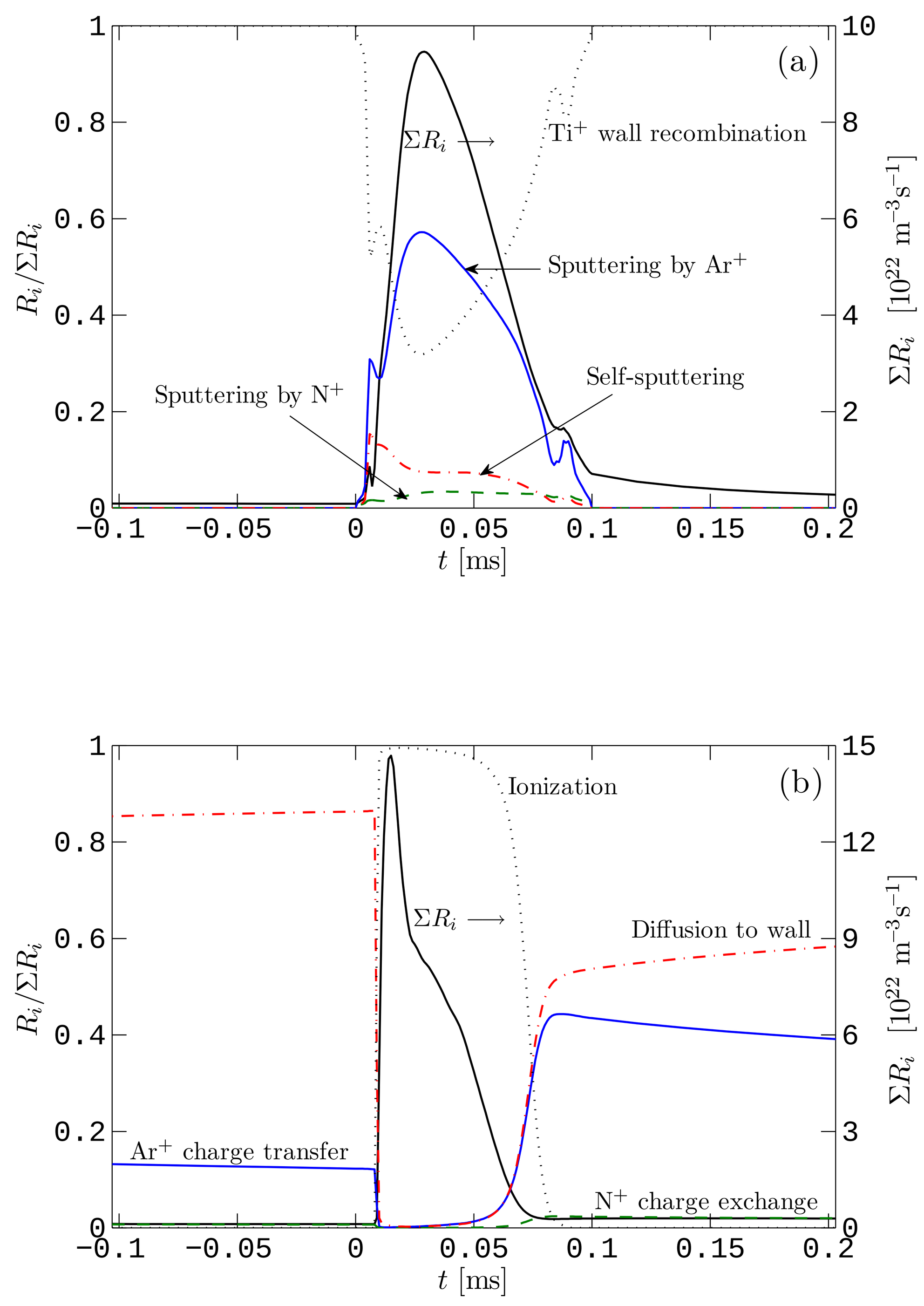

Figure 3: The temporal evolution of (a) the creation of Ti and (b) the loss of Ti atoms over 300 μs at and around the tenth pulse.

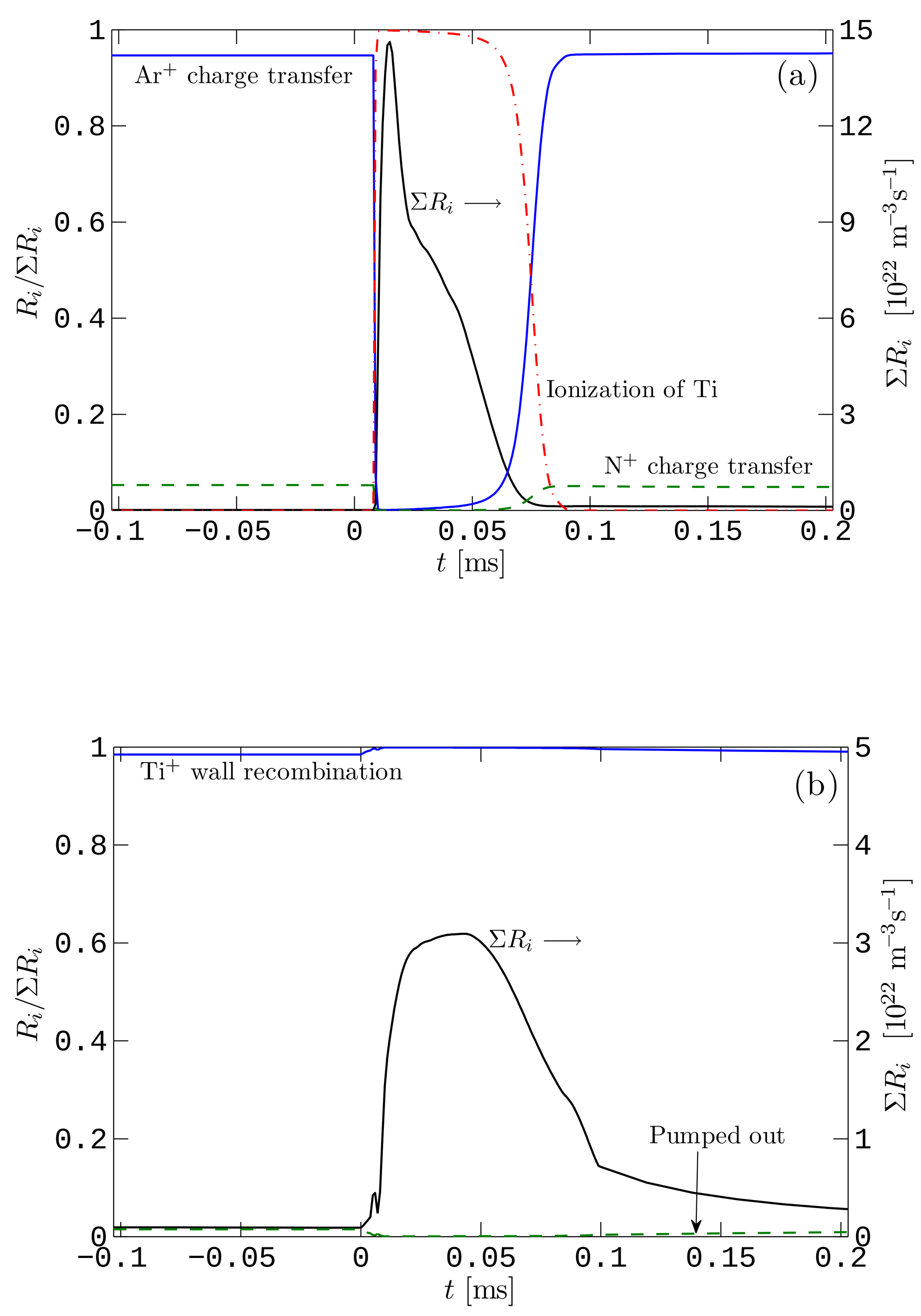

Figure 4: The temporal evolution of (a) the creation of Ti^+ and (b) the loss of Ti^+ ions over 300 μs at and around the tenth pulse.

- The most important reactions for creation of Ti atoms, are wall recombination of Ti^+ and sputtering by Ar^+, Ti^+ and N^+
- The most important reactions for the loss of Ti atoms are electron impact ionization, diffusion to the wall, and Ar^+ and N^+ charge transfer
- Electron impact ionization is the dominating reaction in the creation of Ti^+ ions while the power is on but Ar^+ – Ti charge transfer is the dominating reaction after the power is turned off
- Ti^+ ions are almost entirely lost to wall recombination

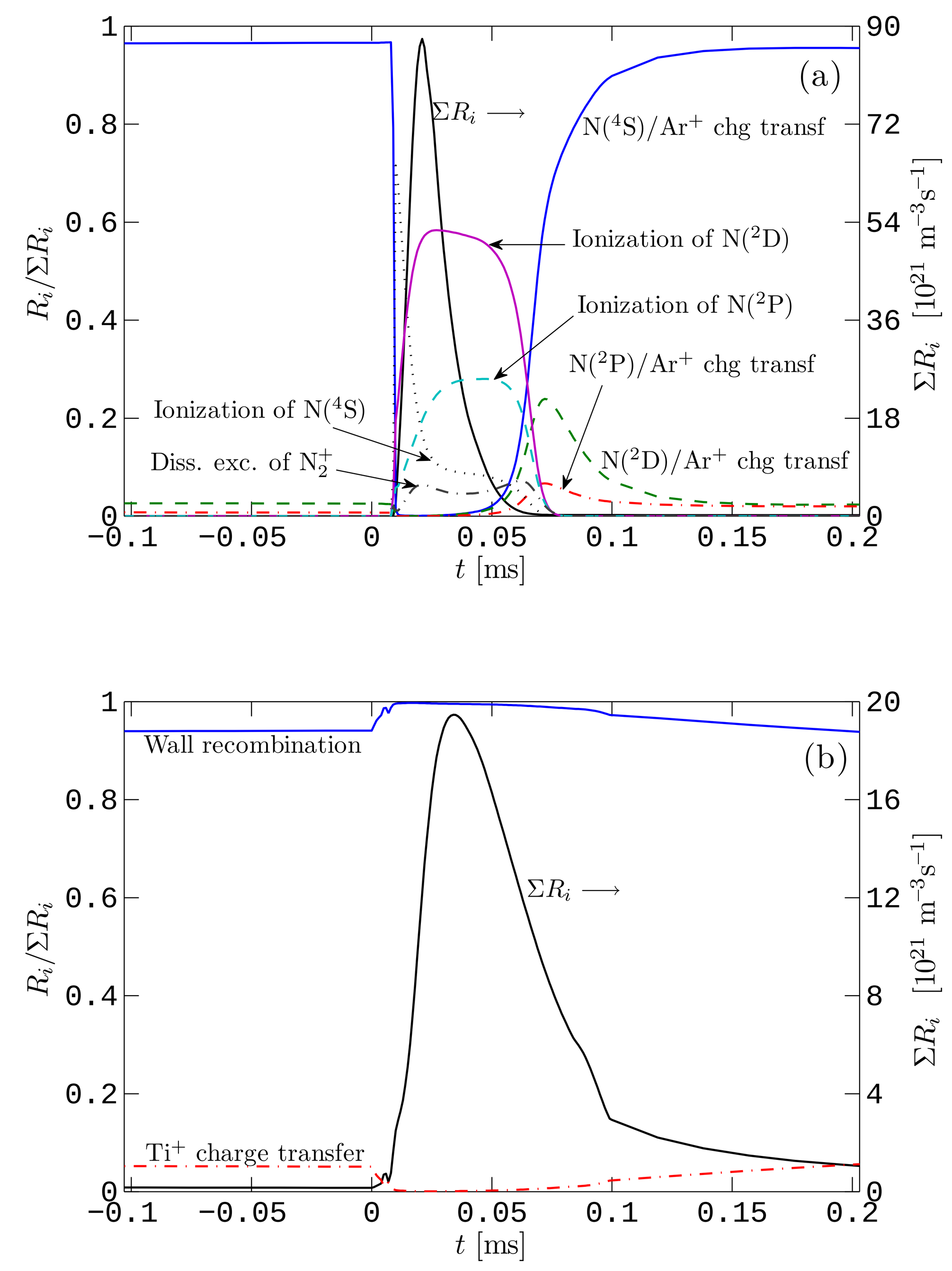

Figure 5: The temporal evolution of (a) the creation of N^+ and (b) the loss of N^+ ions over 300 μs at and around the tenth pulse.

- Electron impact ionization is most important in N^+ production when the power is on, and N – Ar^+ charge transfer when the power is off
- The excited atoms are extremely important for the ionization of N^+, ionization of $N(^2D)$ and $N(^2P)$ being dominant in comparison to ionization of the ground state $N(^4S)$ atom for most of the on-period
- Electron impact ionization of $N(^4S)$ is only most important for the first few μs after the power has been turned on
- The excited atoms are much less important during the off period when essentially all N^+ ions are created by Ar^+ – N charge transfer

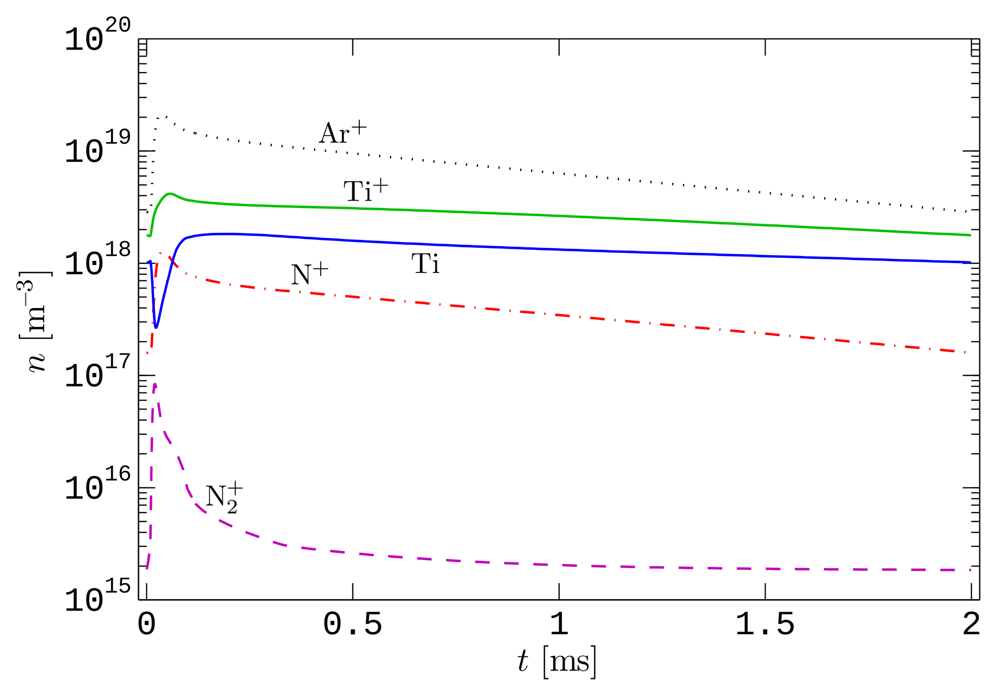

Figure 6: The temporal evolution of the densities of titanium atoms and positive ions over the tenth pulse period.

Conclusions

- A global (volume averaged) model of an N_2/Ar discharge was applied to study the reaction meachanism in a HiPIMS discharge with a titanium target

Acknowledgments

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