A pulsed nitrogen discharge: A global (volume averaged) model study

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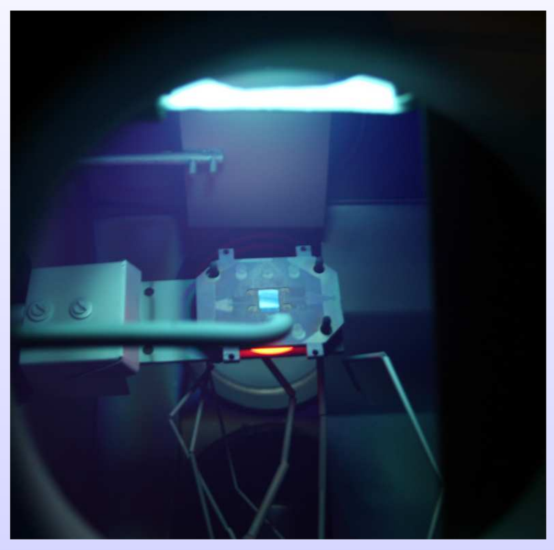

Introduction

- A time dependent global (volume averaged) model is applied to study a pulsed low pressure (1 - 100 mTorr) high density nitrogen discharge.

The global (volume averaged) model

- In addition to electrons the nitrogen discharge consists of molecular nitrogen in ground state $N_2(X^1\Sigma_g^+, \nu = 0)$, vibrationally excited molecular nitrogen $N_2(X^1\Sigma_g^+, \nu = 1-6)$, metastable molecular nitrogen $N_2(A^3\Sigma_u^+)$, atomic nitrogen in ground state $N(^4S)$, metastable atomic nitrogen $N(^2D)$, metastable atomic nitrogen $N(^2P)$, and the positive ions N^+ and N_2^+.
- Electrons are assumed to have a Maxwellian energy distribution in the range 1 – 10 V.
- The time dependent global model is based on previous steady state models (Gudmundsson and Thorsteinsson, 2007) and the work of Ashida et al. (1995) and Kim et al. (2006).

Results and discussion

- The average applied power is 500 W, the duty cycle 25 %, the discharge pressure 14 mTorr, and the gas flow rate 50 sccm.

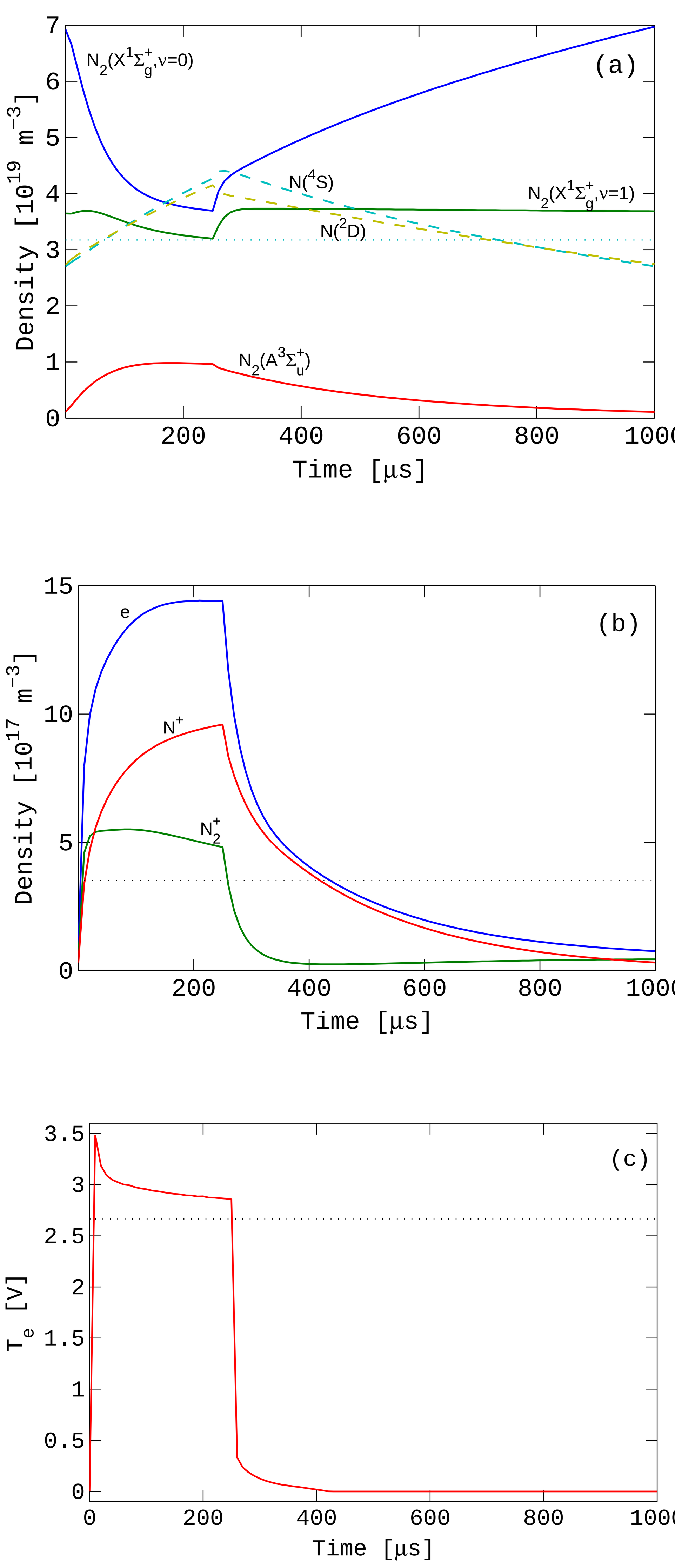

Figure 1: (a) The density of neutral nitrogen atoms and molecules, (b) the density of charged particles, and (c) the electron temperature versus time. The average applied power is 500 W, duty cycle 25 %, discharge pressure 14 mTorr, the pulse frequency 1 kHz, and the gas flow rate 50 sccm. The chamber is assumed to be made of stainless steel, cylindrical with $R = 10$ cm and $L = 10$ cm.

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- The surface recombination coefficient for atomic nitrogen in assumed to be 0.07 (Singh et al., 2000) and the neutral gas temperature 600 K.
- The time evolution of the density of neutral and charged particles and the electron temperature is shown in figures 1 and 2 for pulse frequency of 1 kHz and 100 kHz, respectively.
- The time averaged $N(^4S)$ density is somewhat higher for a pulsed discharge than for a continuous wave (cw) discharge, shown by the dotted line in figures 1 (a) and 2 (a), at the same average power.
- The electron density is significantly higher in a pulsed discharge than for a cw discharge, shown by the dotted line in figures 1 (b) and 2 (b), at the same average power.
- The density of metastable nitrogen atoms $N(^2D)$ (2.38 eV) is only slightly less than the density of nitrogen atoms in the ground state $N(^4S)$.
- The density of the metastable nitrogen molecule $N_2(A^3\Sigma_u^+)$ (6.17 eV) is roughly 3 % of the density of the nitrogen molecule at 1 kHz and 2 % at 100 kHz.
- At low pulse frequency the electron temperature overshoots at the first stage of the on period and then reaches a steady state and eventually decays. At higher frequencies an overshot is not observed.

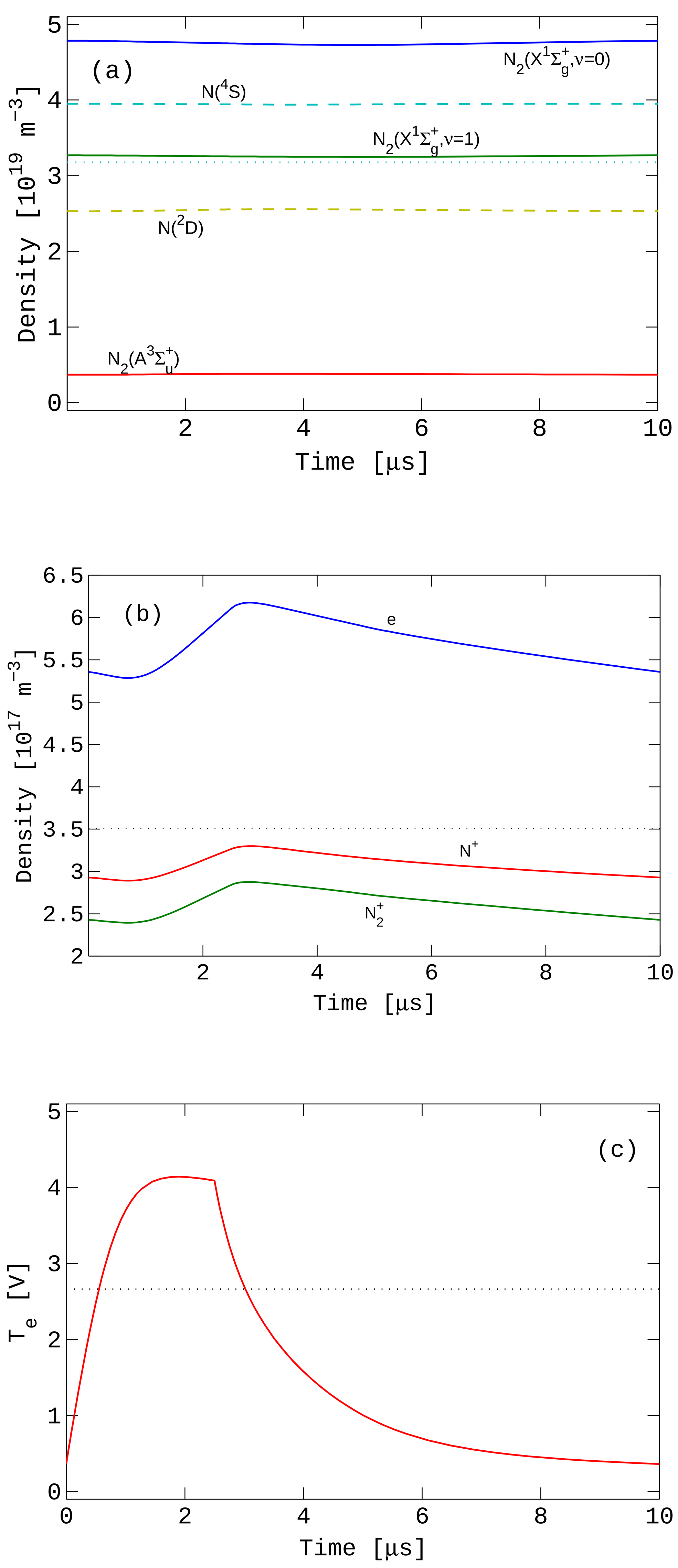

Figure 2: (a) The density of neutral nitrogen atoms and molecules, (b) the density of charged particles, and (c) the electron temperature versus time. The average applied power is 500 W, discharge pressure 14 mTorr, duty cycle 25 %, the pulse frequency 100 kHz, and the gas flow rate 50 sccm. The chamber is assumed to be made of stainless steel, cylindrical with $R = 10$ cm and $L = 10$ cm.

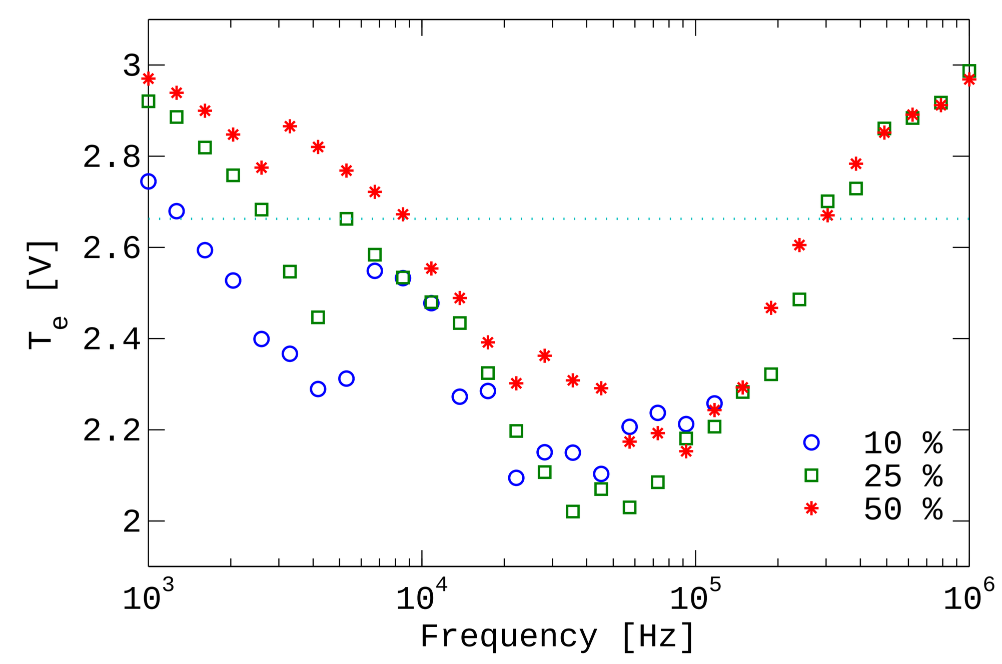

Figure 3: The average electron temperature versus pulse frequency for 10, 25 and 50 % duty cycles. The average applied power is 500 W, discharge pressure 14 mTorr, and the gas flow rate 50 sccm. The chamber is assumed to be made of stainless steel, cylindrical with $R = 10$ cm and $L = 10$ cm.

- For low frequency and high duty cycles the electron temperature is close to that for a cw discharge shown with a dotted line.
- The average electron temperature decreases with increasing frequency and decreased duty cycle to a minimum at roughly 50 kHz and increases again with further increase in the pulse frequency.

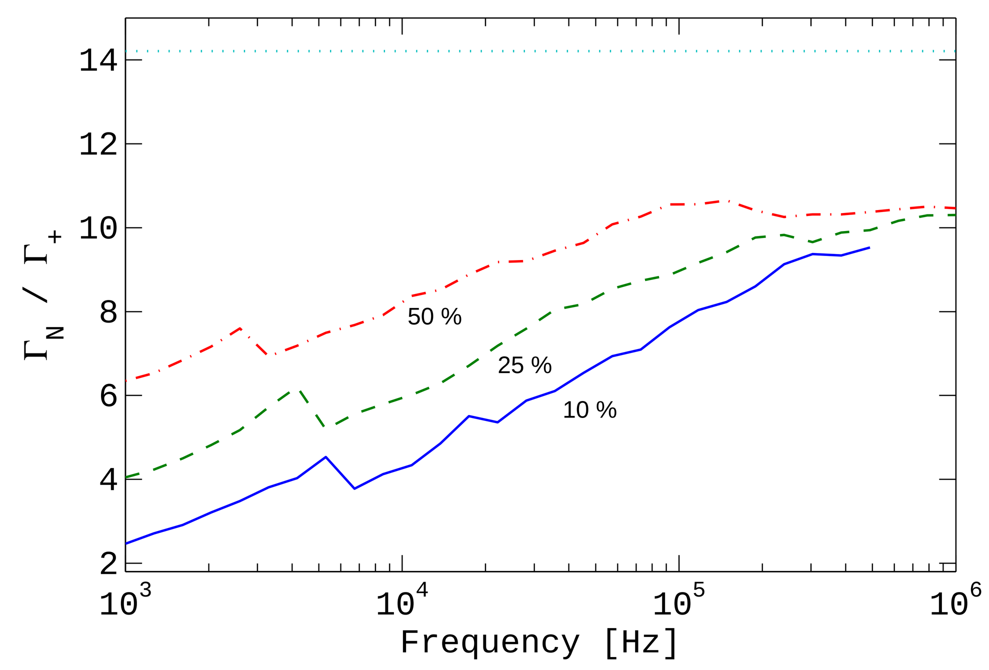

Figure 4: The ratio of time averaged flux of neutral N atoms to positive ions versus pulse frequency for 10, 25 and 50 % duty cycles. The average applied power is 500 W, discharge pressure 14 mTorr, and the gas flow rate 50 sccm. The chamber is assumed to be made of stainless steel, cylindrical with $R = 10$ cm and $L = 10$ cm.

- The average ratio of N neutral flux to total ion flux is below the cw value (shown with a dotted line).

Conclusions

- The density of metastable nitrogen atoms $N(^2D)$ is found to be a significant fraction of the atomic nitrogen density.
- The N neutral to ion flux ratio can be controlled by the pulse frequency and the duty cycle.
- The average N neutral to ion flux ratio increases with increasing pulse frequency and increased duty cycle.

Acknowledgements

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