Oxygen discharges diluted with argon: Dissociation processes

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Introduction

- Addition of Ar to the O_2 discharge, while ashing photoresist, increases the plasma density and etch rate approximately by a factor of 2 (Takechi and Lieberman, 2001).
- Kitajima et al. (2006) report on increased density of metastable $O(^1D)$ atoms in highly argon diluted oxygen plasmas due to quenching of metastable argon atoms.
- These claims are explored using a global (volume averaged) model.

The global (volume averaged) model

- We use a global (volume averaged) model to study the dissociation processes and the presence of negative ions and metastable species in a low pressure high density O_2/Ar discharge.
- In addition to electrons the oxygen discharge consists of molecular oxygen in ground state $O_2(^3\Sigma_g^-)$, metastable molecular oxygen $O_2(a^1\Delta_g)$, $O_2(b^1\Sigma_g^+)$ and $O_2(A^3\Sigma_u^+, A^3\Delta_u, c^1\Sigma_u^-)$, atomic oxygen in ground state $O(^3P)$, metastable atomic oxygen $O(^1D)$, ozone O_3, the positive ions O^+ and O_2^+ and the negative ions O^-, O_2^- and O_3^-.
- We use a significantly revised reaction set for the oxygen discharge (Gudmundsson, 2004)
- The argon discharge consists of argon atom in the ground state $Ar(3s^23p^6)$, metastable argon Ar^m (the metastable levels $1s_5$ and $1s_3$), radiatively coupled levels Ar^r (the levels $1s_4$ and $1s_2$), Ar(4p) and positive argon ions Ar^+.
- Electrons are assumed to have a Maxwellian energy distribution in the range 1 – 7 eV.

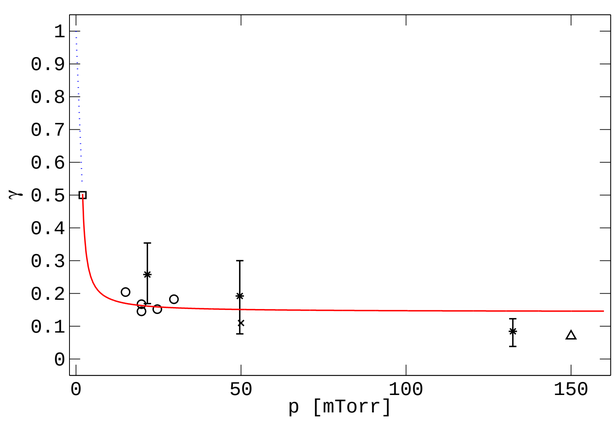

Figure 1: The recombination coefficient of oxygen atoms at the chamber walls for stainless steel as a function of pressure. The measured data is taken from, o Singh et al. (2000), × Matsushita et al. (1997), △ Mozetič and Zalar (2000), □ Booth and Sadeghi (1991) and ∗ Gomez et al. (2002).

- The recombination coefficient of oxygen atoms at the chamber walls is given by a best fit through the measured data in the pressure range 2 – 150 mTorr. For the pressure below 2 mTorr we assume the recombination rate coefficient increases linearly with decreasing pressure from 0.5 at 2 mTorr to 1 at vacuum.

Comparison to experiments

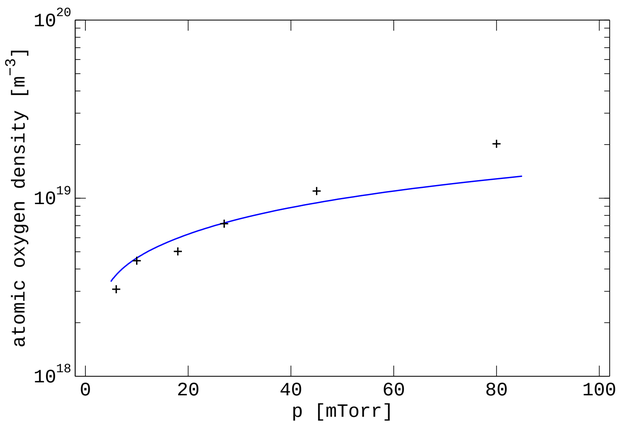

Figure 2: The absolute density of atomic oxygen as a function of pressure argon oxygen ratio $[Ar]/[O_2] = 0.63/0.37$. The measured data + is compared to global model calculation (solid line). The applied power was 150 W and the gas flow rate 33.5 sccm. The inductive discharge chamber was made of stainless steel 20 cm in diameter and 10 cm long. The measured data is taken from Hsu et al. (2006).

Results and discussion

- The chamber is assumed to be made of stainless steel, cylindrical with $R = 10$ cm and $L = 10$ cm.
- The applied power is 500 W, the gas flow rate 50 sccm.

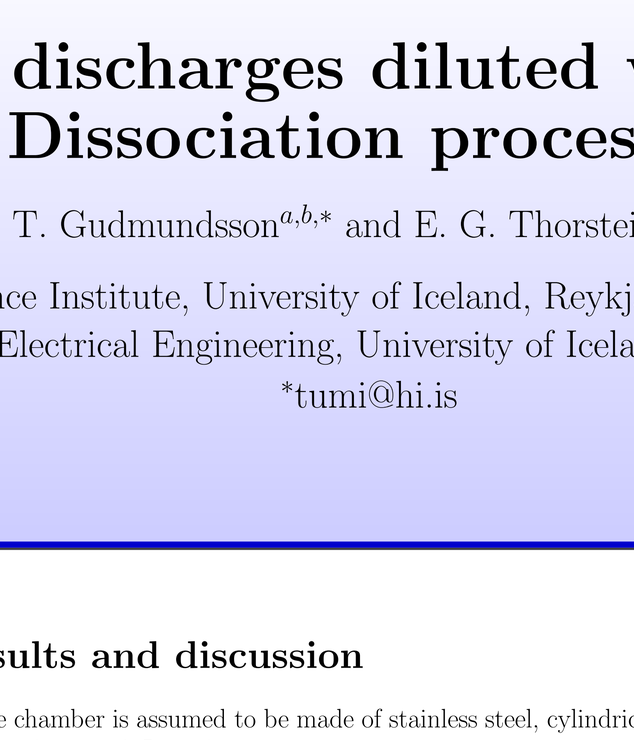

Figure 3: The reaction rates for (a) the creation of the $O(^3P)$ atom and (b) the loss of the $O(^3P)$ atom versus fractional argon flowrate $[Ar]/([Ar] + [O_2])$.

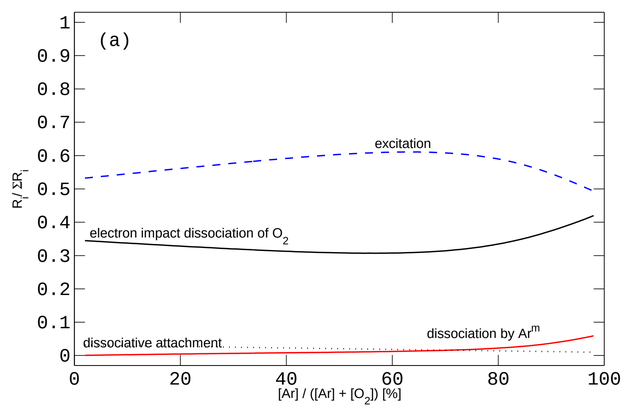

Figure 4: The reaction rates for (a) the creation of the $O(^1D)$ atom and (b) the loss of the $O(^1D)$ atom versus fractional argon flowrate $[Ar]/([Ar] + [O_2])$.

- The majority of the ground state atomic oxygen $O(^3P)$ originates from the metastable state $O(^1D)$
- About 20 – 40 %, depending on the argon content, is created by electron impact deexcitation of the metastable atom $O(^1D)$.
- Quenching of $O(^1D)$ by the O_2 molecule accounts for over 30 % of the $O(^3P)$ creation for pure oxygen discharges and falls to become negligible with increased argon content.
- Electron impact dissociation of the O_2 molecule accounts for roughly 25 – 30 % of the $O(^3P)$ creation
- The destruction of $O(^3P)$ is mainly through wall recombination and electron impact excitation.
- The metastable oxygen atom is created mainly through electron impact excitation of the oxygen atom, roughly 75 – 65 % contribution, decreasing with increased argon content.
- We find the contribution of dissociation by quenching of the argon metastable Ar^m by molecular oxygen to be negligible in the creation of atomic oxygen, both $O(^3P)$ and $O(^1D)$.

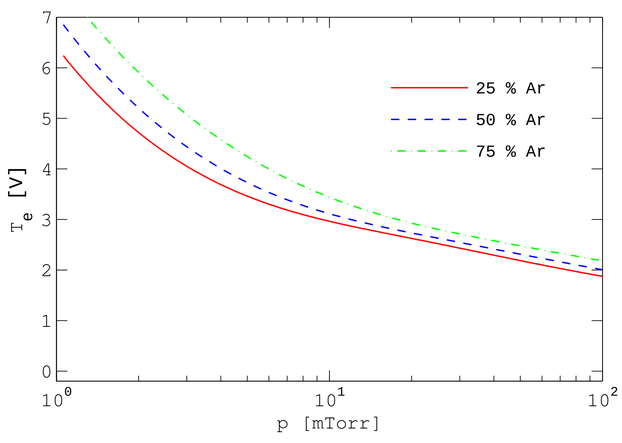

Figure 5: The electron temperature versus pressure. The applied power is 500 W, the gas flow rate 50 sccm and the argon content 25, 50 and 75 %.

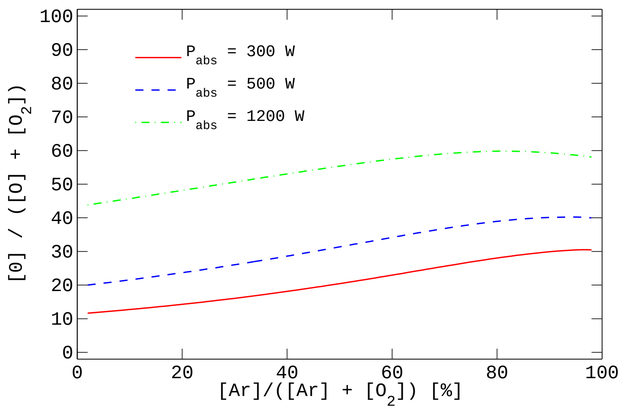

Figure 6: The fractional dissociation versus the fractional argon flow rate.

Conclusions

- The electron temperature increases with increased argon content due to the higher ionization potential of argon compared to atomic and molecular oxygen.
- The fractional dissociation increases with increased argon content due to increased electron impact dissociation with higher electron temperature

Acknowledgments

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