Scaling laws governing the NF3 cleaning plasma in a large area reactor

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Introduction

An important part of the thin film Silicon PECVD technology for photovoltaic industry is the Fluorine based plasma cleaning of the reactor. Precursors like CxFy, SF6, NF3 or even F2 can be used. The present paper investigates scaling laws governing the processes in NF3 plasma in a large area reactor.

Experimental device

The experimental device has been extensively described elsewhere [1], [2]. A schematic drawing of the reactor is shown in Fig. 1. The setup consists of a large area (1.4 m x 1.2 m) reactor with an inter-electrodic gap of few tens of mm, having a capacitively coupled plasma source, at 40.68 MHz in a pressure range between 0.2 mbar and few tens of mbar. SiH4/ H2 mixtures are used for deposition of a-Si/ uc-Si thin films and Fluorine containing plasmas are used for the subsequent reactor cleaning. Different discharge parameters, as for example reactor pressure, gas flows, matching box parameters, DC Bias are continuously monitored. A rest gas analyzer (RGA) was installed in the pumping lines, just upstream to the pump. Emission spectroscopy measurements were also performed.

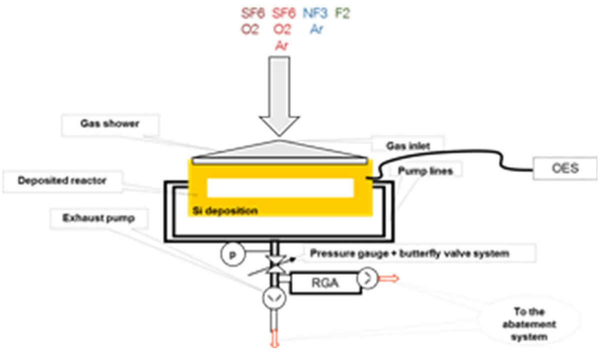

Fig. 1 Experimental device

Reactor pressure as plasma diagnostics tool

If the butterfly valve is kept in fix position, then there is a simple linear relation between the gas flow entering the pump and the reactor pressure. This feature offers the possibility of measuring the total flow at the reactor output; nonetheless some care is needed when using this method. The simple relation between outflow and pressure is valid only if no chemical reaction takes place in the pump, i.e. if no radicals but only stable molecules are present in the gas outlet. This is definitely not the case for the plasma reactor itself, but since the pumping lines are more than 8 m long and have only 0.2 m diameter, it might be true for the whole system: reactor and pumping lines.

We checked this assumption for atomic Fluorine radicals. For the given dimensions of the pumping lines and a gas flow of 5 slm, the residence time in the pumping lines is about 0.6 s. Considering the Fluorine recombination reaction at the walls F + F → F2 and using reaction time of 0.001 s [3] we notice that the reaction time is much shorter than the residence time. In this case we can consider that all of the radicals recombine in the pumping lines and therefore the reactor pressure is a measure of the total outflow entering the pump. Different scenarios (partial dissociation in reactor followed by full recombination in the pumping lines) were considered, as summarized in Table 1. In case the recombination pathway differs from the dissociation pathway and new molecules like N2, F2, N2F4 are produced, then the pressure must increase in the presence of the plasma even in case of full recombination in the pumping lines. Generally speaking, the higher the dissociation efficiency and the higher the weight of the recombination channel leading to F2 and N2 as products, the higher will be the ratio between pressure in the presence and in the absence of the plasma.

Inflow	**Outflow**	p_{Plasma}/p_{gas}
NF3	NF3	1
NF3	0.5 N2 + 1.5 F2	2
NF3	0.5 N2F2 + F2	1.5
NF3	0.5 N2F4+0.5F2	1

Table 1. NF3 radicals: possible scenarios

Not deposited reactor: Gas composition in the exhaust line

As seen in Figure 2.a, the pressure in the presence of the plasma increases (as expected) with both NF3 inflow and applied power. Fig2. b that all of these points “collapse” in a single parametric curve, having on x-axis a Yasuda-like parameter [4] namely the ratio between applied power and NF3 inflow. On y-axis the ratio between the pressure in presence and in absence of the plasma is depicted.

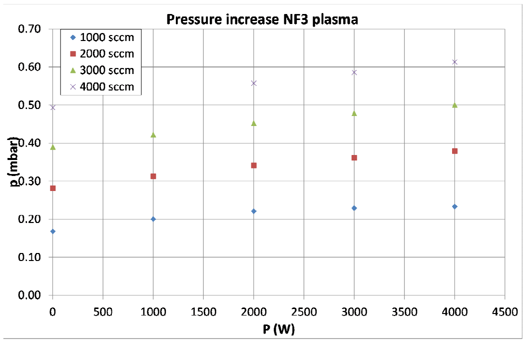

Fig. 2.a NF3 plasma: pressure vs. Flow/ Power

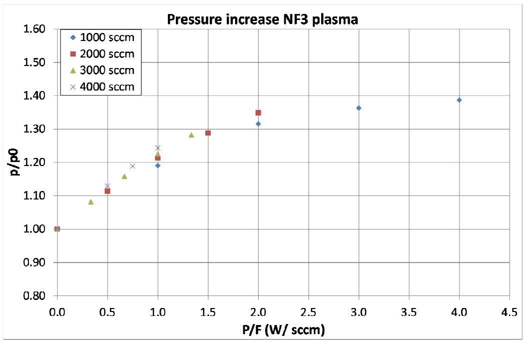

Fig. 2.b NF3 plasma: pressure vs. Flow/ Power

Parametric representation

Two regions of the parameter space can be identified: precursor rich region, for Yasuda-parameters lower than 2 W/ sccm and energy-rich for Yasuda-parameters above the said threshold.

The RGA measurements confirm the above mentioned parameterization. Fig. 3 shows for example the ratio between NF3 outflow and NF3 inflow as a function of the Yasuda-like parameter. For parameters below 2 W/ sccm increasing of Yasuda parameter leads to an increase of NF3 consumption up to 80%. Further increase of applied power (or decrease of NF3 inflow) does not lead to any supplementary increase of NF3 consumption.

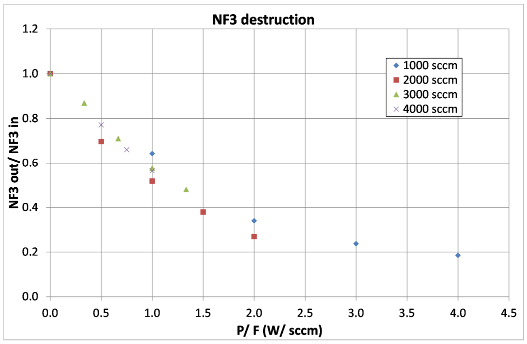

Fig. 3 NF3 destruction vs. Flow/ Power

Parametric representation

Deposited reactor: Cleaning rate

A similar parametrization can be observed when representing the cleaning rate as function of the Yasuda-parameter, as shown in Fig. 4. The cleaning rate increases with the NF3 inflow as long as the Yasuda-parameter remains below ca. 1.6 W/ sccm, and saturates or even decreases for higher flows.

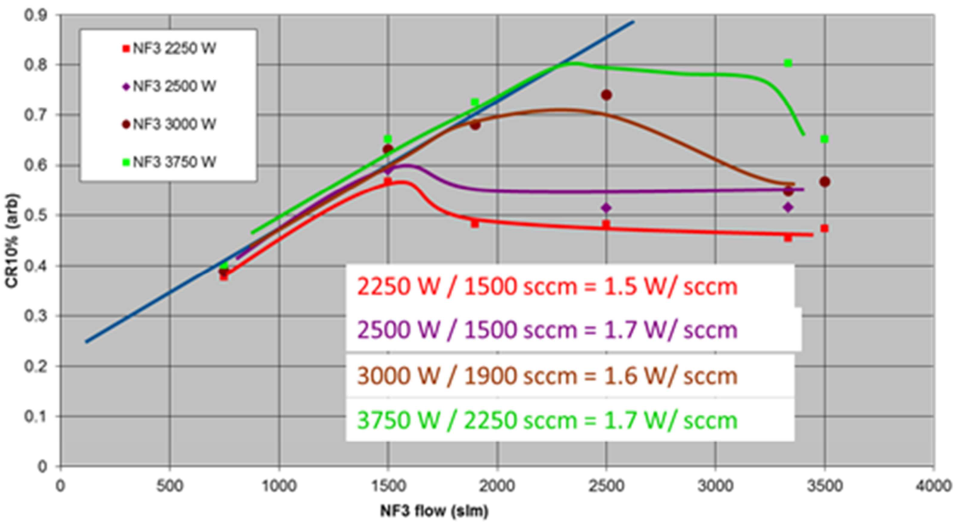

Fig. 4 NF3 cleaning rate

Optical emission spectroscopy measurements

A small amount of Ar was added to NF3 plasma in a not deposited reactor, and OES measurements were performed. Since the conditions for “corona-model” are fulfilled [5], the intensity of Ar lines is directly proportional with the electron density, and the ratio between lines of atomic Fluorine and Ar lines is proportional with the density of atomic Fluorine.

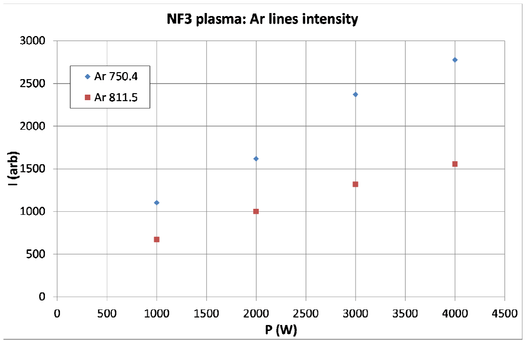

Fig. 5 OES NF3 plasma: Ar lines intensity

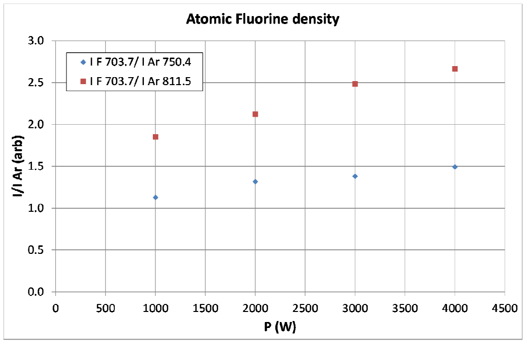

Fig. 6 OES NF3 plasma: density of atomic Fluorine

As can be seen in figures 5 and 6, none of these parameters show any saturation but a linear increase with increasing power. The results are in qualitative agreement with the conclusions global model [5]: increasing the power by constant pressure leads to a linear increase of the electron density and consequently of the density of atomic Fluorine.

Conclusions

Two types of simple scaling laws were experimentally identified in NF3 plasma used for cleaning in large area reactors:

a) the one step electron collision processes like ionization or dissociation scale linearly with the applied power
b) the multi-step molecular processes, as NF3 destruction, F2/N2 production or cleaning show a saturation region by increasing power and scale with a Yasuda-like parameter.

Reference

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