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Neutral oxygen atom density in the MESOX air plasma solar furnace facility

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Abstract

The density of neutral oxygen atoms in the MESOX set-up, one device of the PROMES-CNRS solar facilities, was determined by a fiber-optics catalytic probe (FOCP). Plasma was created in a flowing air within a quartz tube with the outer diameter of 5 cm by a 2.45 GHz microwave generator with the output power up to 1000 W. The flow of air was varied between 4 and 20 l/h. The O-atom density was found to increase monotonously with the increasing discharge power, and it decreased with the increasing flow rate. The degree of dissociation of oxygen molecules in the plasma column depended largely on the flow rate. At the air flow of 4 l/h it was about 80% but it decreased to about 20% at the flow of 20 l/h.

Keywords: Air plasma; Plasma characterization; O-atom density; Degree of dissociation; Catalytic probe (FOCP); Solar furnace

1. Introduction

Recent advances in space technology encouraged serious studies on behavior of high-temperature materials under extreme conditions. The space vehicles entering the upper part of the atmosphere are not only exposed to extremely high temperature, but due to a high velocity they also create plasma as they are heading through air. In order to predict the behavior of the coating materials in such conditions one should take into account both the temperature and the plasma effects. The effect of plasma on high temperature materials is two-fold: first, the plasma radicals recombine or/and relax on the surface causing additional heating, and second, the plasma radicals can alter the degradation resistance of the material due to their high chemical reactivity. A suitable experimental system to study the behavior of such materials under extreme conditions is the MESOX solar facility of PROMES-CNRS in Odeillo [1–4]. It enables combined treatment of materials with air plasma and concentrated solar radiation. The temperature of materials can be varied either by changing plasma parameters, or by changing the solar flux onto the sample, or both.

Plasma created in air at low pressure consists of a variety of radicals with different kinetic and potential (internal) energies. As long as the available energy (i.e., electron temperature) is rather low, the neutral radicals predominate. The list of neutral radicals presented in weakly ionized air includes the vibrationally excited molecules, metastable molecules and atoms. Due to good coupling between the vibrationally excited oxygen molecules and atoms, the molecules quickly transfer their vibrational energy to translation thus heating neutral gas [5,6]. The fact that the dissociation energy of an oxygen molecule is well below that of a nitrogen molecule facilitates dissociation of oxygen. In a recent study of plasma kinetics in low pressure air plasma by Castillo et al., the authors showed that the O density was 20 times larger than the N density [7]. Furthermore, highly vibrationally excited nitrogen molecules may directly dissociate oxygen molecules, especially those in both metastable states ($b'\Sigma_g$ and $a'\Delta_g$). These considerations lead to a conclusion that the density of O atoms in low pressure weakly

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ionized air plasma is high. It is specially the case of microwave plasmas where the electron temperature is often below few eV so the direct dissociation of nitrogen molecules by electron impact is improbable.

Oxygen atoms are stable at low pressure. Due to the energy and momentum conservation they cannot recombine in gas as long as three body collisions are unlikely to occur (at pressure below few 100 Pa). They may recombine on the surface of the discharge chamber. The probability for recombination depends on the material the discharge vessel is made from, its purity, morphology and temperature. Several authors have shown, that the recombination coefficient for O atoms on smooth quartz glass at low temperatures is extremely low [3,8,9] so quartz is probably the best material for building discharge vessels. In such vessels, one can thus expect very high density of O atoms.

The density of neutral oxygen atoms can be measured by different means including a variety of spectroscopies [10–13], NO titration [14–16] and catalytic probes [17–24]. Recently, a comparison between the NO titration and the catalytic probe was performed at CPAT, Toulouse [25]. The O atom density was measured simultaneously by the two methods. It was found that they give practically identical results. Furthermore, the catalytic probes were found to have some advantages over the NO titration: the NO titration is a destructive method, and the probes are not. Since they are very small, they practically do not disturb the original concentration of the O atoms. It was even possible to measure small variations of the O atom density during the titration. As the NO was progressively leaked into the system, the catalytic probe was able to detect small but continuous decrease of the O density [26]. That is the reason why we used a nickel fiber-optics catalytic probe to measure the O-atom density at the present experiments.

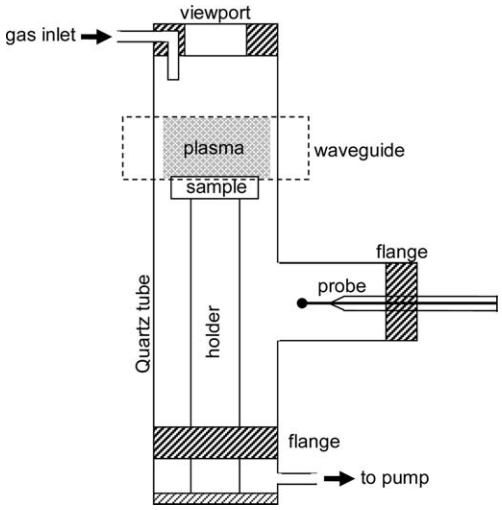

Fig. 1. Part of the experimental set-up.

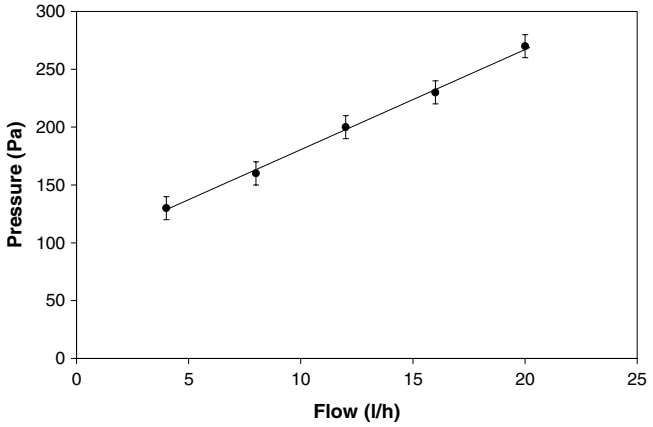

Fig. 2. Evolution of the pressure in the experimental chamber versus the air flow.

2. Experimental results

2.1. Experimental set-up

The experimental system was described in details elsewhere [3]. Due to the completeness of the present paper we briefly describe it here. Schematic of the system is shown in Fig. 1. The system is pumped with a one-stage oil rotary pump with the pumping speed of 12 m^3/h in the pressure range between 50 and 500 Pa. The flow of air through the system is adjusted with a volume flow controller, and the pressure is measured with an absolute vacuum gauge. In the range between 4 and 20 l/h, the pressure increases roughly linearly with increasing gas flow, as shown in Fig. 2. The effective pumping speed at the exhaust of the discharge tube was estimated to about 4–8 m^3/h, depending on pressure. The experimental chamber is a quartz cylinder of length 50 cm and outer diameter 5 cm. Plasma is created within a microwave cavity at 2.45 GHz and the power adjustable between 0 and 1200 W. In our experiments, we used powers between 300 and 1000 W. Inside the quartz tube there is a quartz sample holder. At present experiments it is placed at the lower end of plasma (Fig. 1). The solar radiation is focused on the upper end of the sample holder where the sample is placed during atom recombination evaluation. The concentrated solar flux can reach a maximum value of 5 MW/m^2 in order to heat the sample. A shutter with variable opening is placed on the trajectory of the concentrated solar radiation in order to control the solar flux and so to control the temperature of the sample (from 800 to 2400 K) measured by optical pyrometry at a wavelength of 5 μm. The glass tube has a side arm with the outer diameter of 2.6 cm, placed 10 cm below the upper end of the sample holder as shown in Fig. 1. The tip of a nickel fiber-optics catalytic probe is mounted 10 mm inside the side arm in order to prevent probe degradation.

2.2. The catalytic probe

A nickel catalytic probe was used to determine the density of O atoms at the position of the probe tip. The probe