High enthalpy air plasma / SiC surface interactions

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Conditions occuring during an atmospheric entry in the Earth atmosphere in the vicinity of a spacecraft wall were reproduced in a plasma wind tunnel thanks to induction coupling. While the general purpose is to detail the chemical composition and thermodynamic state of the boundary layer, the presented study deals with radiation then with excited states characteristics. Radiation of atomic species close to the sample surface is shown to be strongly out of equilibrium whereas ionic species recombinate on the surface.

The purpose of the experiments described below is to reproduce the thermodynamic conditions encountered close to a spacecraft wall during an atmospheric entry. The aerodynamic conditions give birth to a shock front behind which a plasma is created due to the temperature rise. Further objectives are to understand the physical and chemical phenomena occuring under non-equilibrium or equilibrium conditions in order to predict the energy fluxes at the wall. Those fluxes are convective due to the high temperature plasma flow around the spacecraft, radiative due to the de-excitation of species excited behind the shock front or in the shock layer and chemical due to the endothermic mainly or exothermic reactions occuring on the surface. The studied phenomena depend on many factors but pressure and specific enthalpy are the most relevant parameters to control. Entry issues are interesting for Earth space activities so air plasmas were produced and studied in free jet situation and in boundary layer situation. In order not to disturb the studied medium, spectroscopic techniques (spontaneous Raman scattering, laser-induced fluorescence and optical emission spectroscopy) were used to obtained data about temperatures and densities of ground and excited states. Only results concerning emission spectroscopy and excited states are presented here. The studied boundary layer takes place in front of a SiC sample exposed to the high-enthalpy air plasma flow.

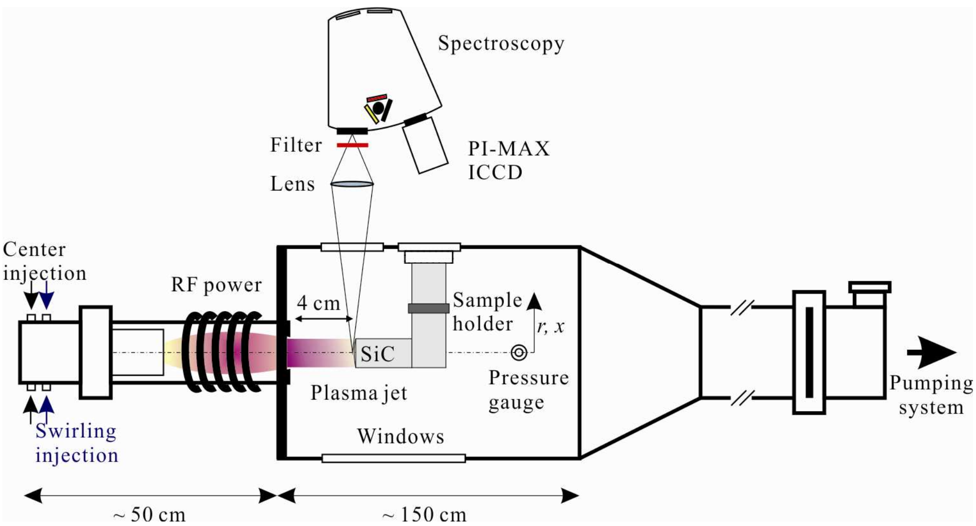

Fig. 1: Overview of the plasma wind tunnel, the SiC sample and the emission spectroscopy setup.

Experiments were carried out in the CORIA research centre 100 kW inductively coupled plasma wind tunnel. The plasma generator is made up of a quartz tube that is 80 mm in diameter surrounded by five-turn water-cooled coils driven by a 1.7 MHz triode oscillator. The gas injection is annular and swirled. The plasma is ignited with argon then switched to synthetic air (80% nitrogen and 20% oxygen). The test chamber (0.5 m in diameter) is water-cooled and equipped with three optical access ports around. They are movable even under low pressure thanks to a dovetail joint. The generator coupling efficiency is estimated to 50%. The pressure is maintained to 900 kPa by a primary/root pumping system. The air mass flow rate is equal to 2.4 g/s and the specific enthalpy is about 18 MJ/kg. An overview of the experimental setup is shown on figure 1.

The free jet was shown to be very close to equilibrium at a temperature of 6000±200 K and to be homogeneous on a radius of 10 mm. Then it can be assumed than the SiC sample is exposed to an homogeneous equilibrium plasma flow. In order to study the behaviour of radiating species, emission spectroscopy was used with a spatial resolution equal to 0.25 mm along the plasma axis. Atomic lines of nitrogen and oxygen were recorded in the near infrared part of the spectrum. The first negative system of N_2^+ was recorded in the ultraviolet part of the spectrum. The post-processing of the recorded spectra leads to results about the radiative density at several wavelengths.

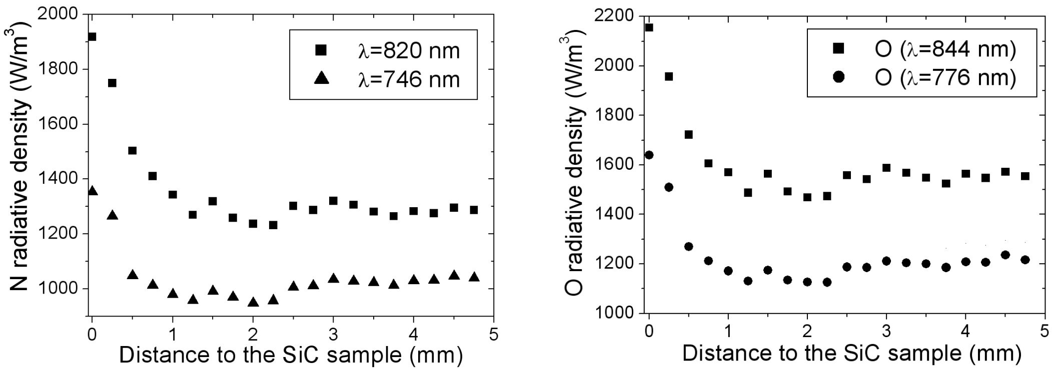

Fig. 2: Radiave density of N (left) and O (right) near infrared lines
on the axis of the plasma flow within the boundary layer in front of the SiC sample

Atomic species have the same radiative behaviour in the boundary layer (figure 2). The radiative density integrated on the emission lines increases obviously closed to the wall. Such an increase has to be correlated with a translation temperature measurement to determine if there is only a temperature effect with a frozen chemistry or a production of excited atomic species close to the wall. In any case such a behaviour cannot be extended to ground state species and then no conclusion about the material catalycity can be drawn at this stage. Nevertheless, such a behaviour pleads for a non-equilibrium process, the sample temperature being lower than the plasma temperature.

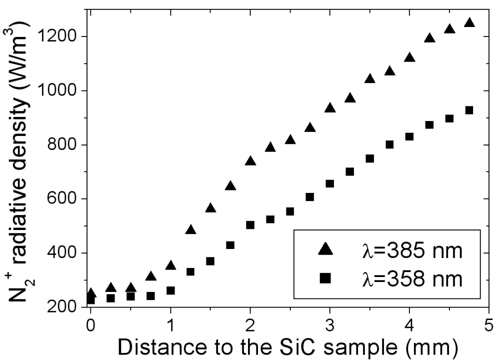

Fig. 3: Radiave density of N_2^+ first negative system on the axis
of the plasma flow within the boundary layer in front of the SiC sample

N_2^+ radiative density conversely decreases from the free jet to the the wall (figure 3) which can be explained by the recombination of the ions on the surface. It should be noticed that N_2^+ is very sensitive to electron history and then to the plasma production process, especially to the injection parameters. Another difference between atomic species and the nitrogen ion is the boundary layer thickness equal to 1.5 mm and 5 mm respectively. To explain those difference aerodynamic time should be compared with characteristic time of chemical processes in the boundary layer. The complete postprocessing of laser techniques and emission measurements will give the necessary data to correctly describe the boundary layer.