Lunar Environment Simulation Capabilities at CASPER. M. Dropmann[1,2], R. Laufer[1], G. Herdrich[1,2], T. W. Hyde[1], M. Cook[1], J. Schmoke[1], [1]Center for Astrophysics, Space Physics and Engineering Research (CASPER), Baylor University, One Bear Place 97310, Waco, TX-76798-7310, [2]Institute of Space Systems (IRS), Universität Stuttgart, Raumfahrtzentrum Baden-Württemberg, Pfaffenwaldring 29, 70569 Stuttgart, Germany.

Introduction: In close collaboration between the Center for Astrophysics, Space Physics and Engineering Research (CASPER) at Baylor University, Texas, and the Institute of Space Systems (IRS) at the University of Stuttgart, Germany, two plasma wind tunnel facilities of similar type have been established using the inductively heated plasma source IPG6, based on proven IRS designs. The facility at Baylor University (IPG6-B) will be subject of this paper. First experiments have been conducted with Air, Ar, O_2 and N_2 as working gases and volumetric flow rates of several L/min at pressures of a few 100 Pa, although pressures below 1 Pa are achievable at lower flow rates. Currently a Pitot probe and a cavity calorimeter are used to characterize the plasma jet. In the near future additional diagnostics will be established and the use of other gases (i.e. H_2, He), and the integration of a dust particle accelerator are planned. The intended fields of research are basic investigation into thermo-chemistry and plasma radiation, space plasma environments and high heat fluxes e.g. in fusion devices or during atmospheric entry of spacecraft.

IPG6-B Test Facility: The IPG6-B test facility has been established in 2011 and is in operation since December 2011. The plasma source IPG6 works inductively. Cold gas is injected into an discharge channel which is surrounded by the induction coil. The strong electromagnetic fields of the coil induce an electric current in the gas and thus ignite the plasma which is exhausted into a vacuum chamber on the other side of the discharge channel. This electrode-less plasma generation allows the production of very pure plasmas without contamination of eroding electrodes. Further even chemical reactive gases pose no problem for this type of plasma source.

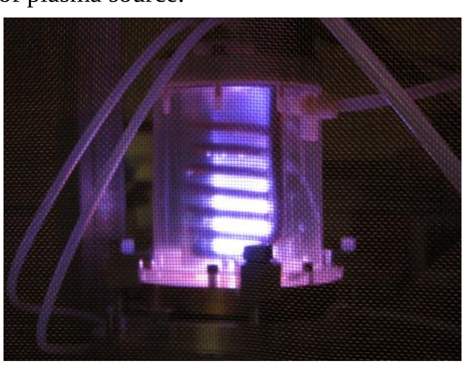

Figure 1. IPG6-B in operation with Air.

The plasma generator is driven by a RF-Generator with an operating frequency of 13.56 MHz and a maximum power input of 15 kW. The generator is placed on a vacuum chamber of 1 m diameter and 2 m length and is pumped by a pump with a pumping speed of 160 m³/h. [1]

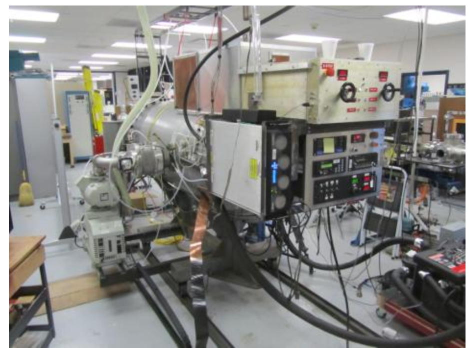

Figure 2. IPG6-B test facility.

The operating gases Air, Ar, O_2 and N_2 have been tested to date and the characterization with Air is currently done. Currently operating pressures are several 100 Pa at volume flow rates of several L/min. Heat fluxes in the order of 2 MW/m² have been achieved. The maximum tested electric input power was 13 kW and the efficiciency is in the order of 20% to 30%.

Diagnostics: Currently three types of diagnostics are available to characterize the IPG6-B facility. These instruments are described briefly below.

Calorimeter: In order to measure the total plasma power of the IPG6-B a cavity calorimeter has been developed consisting of a water-cooled copper cone. The plasma enters the cone and exchanges energy with the copper walls. Based on the increase of cooling water temperature and cooling water flow rate the plasma power can be estimated. [2]

Pitot Probe: Using a Pitot probe dynamic pressure profiles in the plasma jet can be determined [3]. Further, measuring the cooling water temperature increase in this probe, rough heat flux estimations are possible.

Oxygen Sensor: VacuSEN is a miniaturized unique sensor system that was developed based on the space experiment FIPEX on ISS. It enables measurements of both the molecular and atomic oxygen concentrations inside the plasma chamber. The working principle is an amperometric solid electrolyte sensor that is able to measure a partial pressure down to $1x10^{-6}$ mbar pO_2.

Due to the space driven miniaturization and reference free measurement principle, the robust ceramic sensor can be used for direct time resolved in-situ measurements. First tests have been done in the IPG6-B test facility. [4]

Future Diagnostics: In the near future, implementation of a Langmuir probe and a heat flux probe are planned. Further, additional optical diagnostic techniques might be of interest, for example, emission spectroscopy, laser induced fluorescence or Thomson scattering.

Additional Equipment: In order to expand the capabilities of the IPG6-B test facility additional equipment will be available.

Light Gas Gun: The light gas gun (LGG) can accelerate small particles or dust using a pressurized inert gas. Particles of 0.6 to 2.4 mm size have been accelerated to about 780 m/s [5]. Dust particles of 74 µm have been accelerated to 130 m/s [6]. The velocity can be measured using two laser curtains.

Side Arm: A diffusion tube can be connected to the side of the vacuum chamber. Plasma will diffuse into this arm and due to surface interactions a concentration gradient will be created [4]. Further a pumped sidearm could be used in order to create low pressure environments.

Applications: IPG-B offers many opportunities for investigations. At CASPER the following applications are of main interest.

Catalysis: Using the side-arm technology and the VacuSEN System gives the opportunity to collect data determining the oxygen amount along the side-arm. By placing a sample into the tube the change in oxygen concentration before and after the probe can be measured. Depending on the concentration, catalytic surface properties of the sample material can be calculated.

Atmospheric Entry: One of the most important investigations in human and unmanned space exploration is the field of atmospheric entry. Using heat shields, which resist the heat flux during entry, is vital for the success of any mission. Being capable of using various gases, even chemically reactive ones, the IPG6-B test facility provides the opportunity to generate a high enthalpy plasma of various compositions to simulate entries into different atmospheres e.g. Earth and Mars.

Satellite Hardware: The large vacuum chamber and side-arm subsystem at IPG6-B are important assets to create low plasma densities, assuming a decrease of the plasma density with greater distance from the plasma source. The reproduction of plasma conditions, that have relevance for both aerothermodynamics and plasma environments in space, allows investigation of ambient plasma properties that are common in different orbits, e.g. the Lower Earth Orbit (LEO), that is of interest for investigations of effects on satellite hardware.

Divertor Simulator: Similar to the heat shield of spacecraft the divertor of a fusion reactor is subject to heat fluxes on the order of several MW/m². Thus, using hydrogen and helium as operating gas conditions similar to those in a divertor are achievable. Further the light gas gun allows further to simulate the accelerated dust particles in the divertor region.

Lunar Applications: The moon is a promising target of future exploration. Thus the lunar environment is of special interest. It has an extremely thin atmosphere with a particle density of $1x10^4$ m^{-3} during day and $2x10^5$ m^{-3} during night [7]. Further the solar wind hits the surface with velocities of several 100 km/s only protected locally by mini-magnetospheres. Dust particles with a mean size of 60 to 80 µm are present with velocities of several km/s.

Using plasma wind tunnels the mentioned mini-magnetospheres have already been simulated in laboratory experiments [8]. The operating parameters of the IPG6-B facility are promising to create similar conditions.

A side-arm could be used to create lower plasma concentrations than in the jet of the plasma source. Thus far lower plasma concentrations can be achieved. Collected data can be used to verify numerical tools which then can be applied to the conditions on the lunar surface.

The LGG can accelerate Lunar simulant to relevant velocities. Thus the impact of high velocity Lunar particles can be simulated in order to assess resulting surface damages.

Besides the IPG6-B facility two GEC reference cells are available at CASPER. In these plasma cells dust charging experiments are done. Consequently the charging properties of Lunar simulant could be analyzed in order to assess the phenomenon of levitating dust on the Lunar surface.

References:

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