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ScienceDirect
Journal of Nuclear Materials 363–365 (2007) 1457–1460
journal of nuclear materials
www.elsevier.com/locate/jnucmat

Catalytic probes for measuring H distribution in remote parts of hydrogen plasma reactors

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Abstract

Catalytic probes for measuring the H density in remote parts of hydrogen plasma reactors are presented. The probe allows for determination of the H density in its vicinity by measuring the heat dissipated on its tip due to catalytic heterogeneous surface recombination of H atoms. Since the probe is made small, it does not disturb the original concentration of the atoms much. By moving the probe through the vessel it is possible to measure the distribution of H density in the entire vessel. The probe was successfully applied for measuring the H density in remote parts of different hydrogen plasma reactors. Depending on discharge parameters, different values were obtained ranging from 1×10^{20} to 6×10^{21} m^{-3}. The H density depends on the recombination coefficient of the discharge vessel. In the case of borosilicate glass, the recombination coefficient is stable and low enough to enable a high H density. In the case of Pyrex, the recombination coefficient increases with the chamber temperature leading to a huge decrease of H density as the wall is heated.

PACS: 52.20.H; 52.25.Y; 52.70.Nc

Keywords: Divertor neutrals; Hydrogen; Probes

1. Introduction

Hot plasma in fusion reactors is fully ionized. The hydrogen (deuterium, tritium) ion temperature in bulk plasma often exceeds 10 keV, while in the divertor the plasma is cooler and the ion temperature lower. Hydrogen ions collide with the divertor wall where they are neutralized. The neutralization probability slightly varies with the incidence angle, but is always high. The kinetic energy of the resulting neutral atom strongly depends on the incidence angle. It is highest at the glancing angle and lowest at the normal incidence. The fast neutrals are quickly thermalized at subsequent wall collisions. The surface neutralization is therefore a source of neutral rather cold hydrogen atoms. Some fast hydrogen ions are not scattered from the surface, but implanted into the plasma facing material. They can desorb either in the form of molecules or atoms. Measurements in TEXTOR [1–8] showed that the atomic hydrogen flux from the carbon, deduced from Balmer line H_α measurements, is comparable

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doi:10.1016/j.jnucmat.2007.01.206

to molecular flux at low carbon temperature. By heating of the test limiter surface the molecular intensity dropped and the intensity of atomic species increased. At high temperatures (above carbon temperature of 1500 K) the atomic release dominates and molecules are practically negligible. Such behaviour was also found in ion beam experiments [9].

The density of H atoms in remote parts of fusion reactors is therefore high enough that it must be taken into account at plasma modelling. Unfortunately, many methods for quantitative determination of H density are difficult to apply in fusion reactors. The optical emission, which can be applied, is a relative method and can be quantified only after elaborate modelling. A sophisticated physical model for determination of the absolute value of H density in hydrogen plasma was applied recently [10]. In this reference, the authors described a method for calculating the atom density from measurements of the absolute Balmer line intensities and from line ratios.

The only direct method for measuring H density which can be applied in remote parts of fusion reactors, i.e. parts where the ion density is much lower than the atom density and the radiation from hot plasma is screened, is the catalytic probe. It allows for measuring H density in a broad range from about 10^{17} to 10^{22} m^{-3} as long as certain conditions are fulfilled. The probe is introduced in the present paper and some results of H measurements in plasma afterglows are presented.

2. Catalytic probe

Catalytic probe is a simple device capable of measuring the H density in a rather broad range. It can be just a small piece of catalytic metal connected to thermocouple wires as shown in Fig. 1. More elaborate probes are made from optical fibre whose tip is covered with a catalytic material

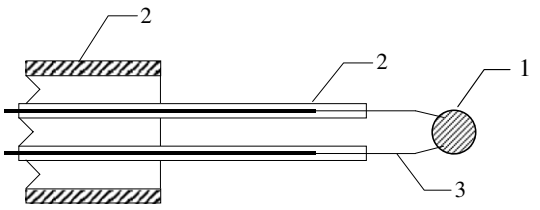

Fig. 1. A simple thermocouple probe. (1) Catalyst, (2) probe holder and (3) thermocouple wires.

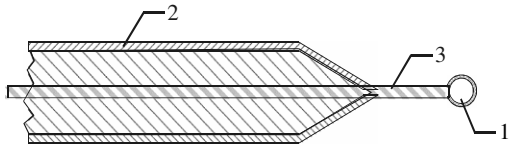

Fig. 2. A fiber optics catalytic probe. (1) Catalyst, (2) probe holder and (3) optical fibre.

(Fig. 2). In both cases, the catalytic material has a high recombination coefficient for the surface reaction $H + H \rightarrow H_2$. There is a choice of different catalytic materials, and they have to fulfill the following requirements: the recombination probability should not significantly depend on temperature, the material structure and the surface morphology should not change significantly at exposure to a high flux of H atoms, the melting point should be high, the vapour pressure at elevated temperature should be low, and the material should be either oxidation-resistant or should form an oxide film that is easily reduced at exposure to hydrogen atoms. These requirements limit the choice of appropriate catalytic materials to metals such as noble metals and nickel. We are often using pure gold as the catalytic material.

The simple operation principle makes the measurements pretty reliable: when the probe tip is exposed to atmosphere rich with H, the hydrogen atoms recombine on the catalyst surface. The excessive energy heats the catalyst material. The probe tip is therefore well above the ambient temperature. Using appropriate physical formalism it is possible to calculate the H flux onto the probe tip, as demonstrated elsewhere [10–13]. The best catalytic material for application with probes for measuring the H density in remote parts of fusion reactors is probably pure gold. It has a high and stable recombination coefficient and is not sensitive to a high magnetic field.

3. Application of the catalytic probe

Fig. 3 represents measurements of the H density in the afterglow of inductively coupled RF hydrogen plasma. The RF power was fixed at 300 W. Plasma was created in a cylindrical discharge tube made from borosilicate glass Schott 8250, which has a low recombination coefficient. Pressure is measured with a Pirani gauge, which was previously calibrated for hydrogen versus a baratron. The gauge is placed in a side vessel of the experimental

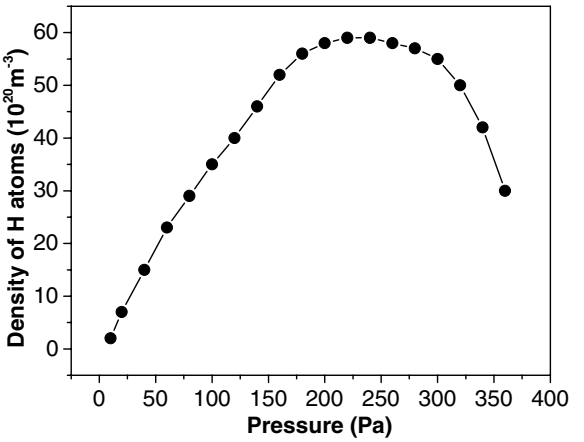

Fig. 3. Density of neutral hydrogen atoms in the afterglow of RF plasma created in a borosilicate chamber at discharge power of 300 W.

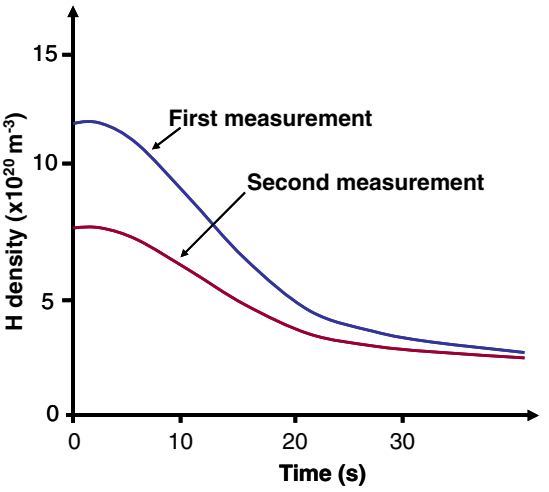

Fig. 4. H density versus time in a hydrogen plasma afterglow created in Pyrex chamber. Upper curve – result obtained at first measurement, lower curve – result obtained at second measurement performed 2 min after the first measurement.

system kept at room temperature, away from the discharge chamber. A recombinator for H atoms is mounted between the discharge chamber and the gauge to assure negligible H density in the gauge. The resulting H density in the afterglow region reaches the value of about 6×10^{21} m^{-3} at the pressure of few 100 Pa. The H density depends on pressure: at low pressure it increases with increasing pressure rather linearly, reaches a broad maximum, and decreases with further pressure increase. Such behaviour is typical for many cold plasma reactors. At low pressure, the dissociation degree does not depend much on pressure, but is limited by surface recombination of the hydrogen atoms. Plasma reactors made from material with a high recombination coefficient will never give cold plasma with such a high H density. As the pressure approaches 150 Pa, the linearity is lost. In the region from 150 to about 300 Pa, the H density is rather constant. In this region, the density depends on power. Higher power will produce plasma with a higher H density. At even higher pressure, the H density decreases rapidly as pressure increases. This phenomenon is explained by three effects: first, plasma shrinks to a smaller volume, second, the electron temperature decreases with increasing pressure due to a smaller ratio between the electron mean free path and its oscillating amplitude, and third, the H atoms recombine in the gas phase since the three body collisions become important. In any case, the H density is not time dependent at fixed discharge parameters.

Fig. 4 represents the density of neutral hydrogen atoms in a Pyrex tube. In this case, the H density decreases with time. This is due to surface recombination of H atoms on the inner walls of the Pyrex tube. The recombination coefficient (γ) for H atoms on Pyrex increases with increasing surface temperature. At the beginning, the Pyrex glass is at room temperature. As plasma is turned on, H atoms recombine on the surface and cause heating of the Pyrex glass. As the temperature is increased, the recombination of H atoms on the Pyrex surface is increased too, leading to further increase of temperature and further increase of the recombination probability. The result of increasing surface recombination is a dramatic decrease of H density as shown in Fig. 4. The measurement was repeated after 2 min so that the Pyrex was cooled, but not down to room temperature. The lower curve in Fig. 2 represents the measured H density after the cooling of the Pyrex glass. As expected, the initial H density is now lower then it was at the first measurement. The H density is therefore very sensitive to the recombination coefficient of the vacuum chamber.

Catalytic probes give best results in the afterglow region of a plasma reactor, where the density of ions is negligible, there is practically no light emission and the neutral gas temperature is close to the reactor wall temperature. In fusion devices, such conditions are found in remote parts, well screened from hot plasma. Examples include the remote parts of the divertor, remote parts of mirror cavities and the pump duct. The H density can be measured in

a side arm of a plasma device, and the value of H in the main chamber is calculated using appropriate model of atom diffusion along the side arm [14]. If the requirements are fulfilled, the accuracy of this method depends largely on accuracy of determination of the recombination coefficient for the particular material used as the catalyst. Since the accuracy of this measurement is about 20%, the absolute accuracy of the method is never better than about 25%. This is satisfactory in many cases, as the H atom density is very sensitive to environment and strong gradients are often observed.

4. Conclusion

Catalytic probes for measuring the absolute value of H atom density were briefly described. The probes can be applied for measuring the H density in cold, remote parts of fusion devices. The recommended catalytic material is pure gold since it has a stable and high recombination coefficient and is immune to strong magnetic fields. The probes can measure the H density at reasonable accuracy in the wide range from about 10^{19}–10^{22} m^{-3}. The lower limit is defined by sensitivity of temperature reading and other effects that might affect the catalyst temperature, while the upper limit is often the catalyst melting.

Acknowledgement

This work has been funded by Slovenian Fusion Association.

References

[1] A. Pospiesyczyk, S. Brezinsek, Ph. Mertens, G. Sergienko, Contrib. Plasma Phys. 42 (2002) 663.
[2] E. Vietzke, Contrib. Plasma Phys. 42 (2002) 590.
[3] Ph. Mertens, A. Pospieszczyk, J. Nucl. Mater. 269 (1999) 884.
[4] J.D. Hey, C.C. Chu, E. Hintz, Contrib. Plasma Phys. 40 (2002) 9.
[5] E. Hintz, B. Schweer, Plasma Phys. Contr. Fus. 37 (1995) A87.
[6] U. Fantz, B. Herger, Plasma Phys. Contr. Fus. 40 (1998) 2023.
[7] A. Pospiesyczyk, Ph. Mertens, G. Sergienko, A. Huber, V. Phillips, D. Reiter, D. Rusbuldt, B. Schweer, E. Vietzke, P.T. Greenland, J. Nucl. Mater. 266 (1999) 138.
[8] S. Brezinsek, Ph. Mertens, A. Pospiesyczyk, G. Sergienko, Contrib. Plasma Phys. 42 (2002).
[9] P. Franzen, E. Vietzke, J. Vac. Sci. Technol. A 12 (1994) 820.
[10] K. Behringer, U. Fantz, New J. Phys. 2 (2000) 23.
[11] M. Mozetic, M. Drobnic, A. Pregelj, K. Zupan, Vacuum 47 (1996) 943.
[12] D. Babic, I. Poberaj, M. Mozetic, Rev. Sci. Instr. 72 (11) (2001) 4110.
[13] M. Mozetic, U. Cvelbar, A. Vesel, A. Ricard, D. Babic, I. Poberaj, J. Appl. Phys. 97 (2005) 103308.
[14] A. Drenik, U. Cvelbar, A. Vesel, M. Mozetic, Inform. Midem 35 (2005) 85.