# Diamond-coated probe head for measurements in the deep SOL and beyond

R. Schrittwieser[1], G.S. Xu[2], N. Yan[2,3], V. Naulin[3], J.J. Rasmussen[3], P. Schrittwieser[4], D. Steinmüller-Nethl[4], F. Mehlmann[1], C. Ionita[1]

[1]*Association EURATOM/ÖAW, Institute for Ion Physics and Applied Physics, University of Innsbruck, Austria*

[2]*Institute of Plasma Physics, Chinese Academy of Sciences, Hefei, People's Republic of China*

[3]*Association EURATOM/DTU, Department of Physics, DTU Risø Campus, Technical University of Denmark, Roskilde, Denmark*

[4]*KOMET RHOBEST GmbH, Exlgasse 20a, 6020 Innsbruck, Austria*

**Abstract:** We have tested two cylindrical graphite probe heads coated by a layer of electrically isolating UNCD (Ultra Nano-Crystalline Diamond) using a CVD (Chemical Vapour Deposition) method. The probe heads were mounted on the reciprocating probe manipulator of the Experimental Advanced Superconducting Tokamak (EAST) in Hefei, People's Republic of China. Transport parameters, plasma density, temperature, potential, as well as toroidal rotation near the separatrix were determined up to a distance of 15 mm inside the LCFS in high confinement regimes. A very important result was that the UNCD coating could also prevent the sputtering of graphite from the probe head and the subsequent coating of the BN isolation between probe pins and probe head by a layer of conductive graphite almost completely.

## 1. Introduction

In tokamaks probes have successfully been used in the SOL (Scrape-Off Layer), where radial particle transport, Reynolds stress and radial transport of poloidal momentum have been determined (see e.g. [1,2,3,4]). Measurements inside the LCFS (Last Closed Flux Surface) have up to now been ventured but rarely, because of the strong particle bombardment of the probe. If the probe pins and their housing are of graphite, sputtering and evaporation can not only lead to damages, but the sputtered-off electrically conductive graphite can also deposit on the boron nitride material usually used for electrical isolation and lead to unwanted shunts. Recently in ASDEX Upgrade a graphite probe head with 6 graphite pins was inserted up to about 4 mm inside the shear layer [5]. After several shots the probe pins were visibly sputtered in such a way that tips were "sharpened" while the length was not altered.

The probe heads described in the following stemmed from the Experimental Advanced Superconducting Tokamak (EAST) in Hefei, People's Republic of China. They were sent to

Innsbruck for being coated and then sent back to Hefei, where they were mounted on the reciprocating probe manipulator with interesting and promising results.

## 2. Experimental results

The two probe heads have diameters of 3 cm (See Fig. 1) and an overall length of 10 cm. The coating with Ultra-Nano Crystalline Diamond (UNCS) was carried out by the KOMET RHOBEST Company in Innsbruck. The duration of coating was 14 hours. The thickness of the UNCD layer is in the range of 10 to 15 μm, extending over the front side of the probe heads and on the side walls up to about 3 cm towards the rear sides. One of the probe heads carries three Langmuir probes of which one is protruding radially. The other probe head is used as Mach probe carrying five graphite pins. The two UNCS-coated graphite probe heads are shown in Fig. 1 before the insertion of the probe pins.

*Fig. 1: Two graphite probe heads for EAST with 3 cm diameter each and overall lengths of 10 cm, here shown without the probe pins inserted.*
*Left the probe head for three Langmuir probe pins, right the probe head for the 5-pin Mach probe.*

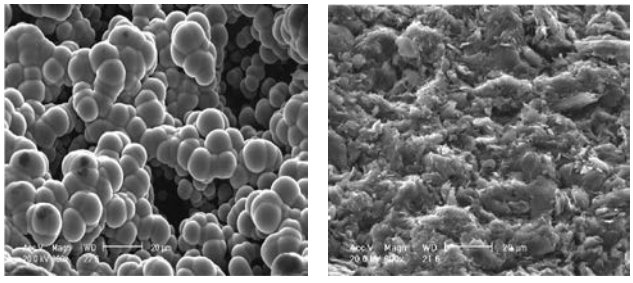

*Fig. 2: SEM (Scanning Electron Microscope) of the probe surfaces before use.*
*UNCD-coated surface on the left-hand side.*
*Uncoated graphite on the right-hand side.*

Before the first insertion of the probe heads, the pure graphite and UNCD coated parts of the surfaces of the two probe heads were investigated under a SEM (Scanning Electron Microscope). Fig. 2 shows the results. The UNCD (left panel) layer appears in form of spheres, since always a number of diamond crystals of 5 nm diameter each forms clusters. The surface roughness appears rather high, but this can be mended. The typical appearance of an uncoated graphite surface (right panel) is strongly different from the UNCD-coated surface and easily distinguishable.

The coated probe heads have been used in several discharges in EAST in L-mode and H-mode. The probe heads were inserted up to 15 mm inside the last closed flux surface (LCFS) and have performed very well. The most important insights concerning the probe surfaces were the following:

- *Positive effects:* The UNCD coated surfaces were almost not sputtered. In earlier discharges with uncoated probe heads during deep insertions a very bad effect was that graphite from the surface of the probe head was sputtered and re-deposited also on the boron nitride isolators of the probe pins thereby creating unwanted electric shunts. This effect could be almost completely prevented with our UNCD-coated probe heads.
- *Negative effects:* The UNCD diamond layer partially dropped off during experiment in particular on edged spots. However, with improved coatings this can hopefully be prevented in future.

*Fkg. 3: The five pin probe head with the spot were the UNCD-coating dropped off marked .A SEM of this spot is shown in Fig. 4.*

As an example Fig. 3 shows the five-pin probe head where a piece of the UNCD-coating has fallen off (marked by a red ellipse) during the insertion inside the LCFS. This occurred at an edge of the probe head.

Fig. 4 shows an SEM scan of this spot where still also a part of the UNCD-coated surface is visible, distinguishable by the characteristic spherical diamond clusters (see Fig. 2).

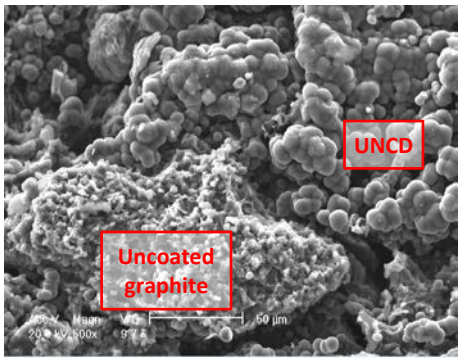


*Fig. 4: SEM of the spot marked in Fig. 3. The difference between the still UNCD-coated part and the uncoated is well distinguishable.*

Fig. 5 shows an example of a measurement with the 3-pin probe head during EAST shot #40847. We clearly see a transition from the L-mode to the intermediate mode (I-mode) at $t$ = 2,520 s and then to the H-mode at $t$ = 2,564 s. Shown are the temporal evolutions of the $D_\alpha$-line, the floating potential $V_{fl}$ and of the spectrum of the floating potential. We clearly see the enhanced fluctuation level in the $D_\alpha$-line intensity and in $V_{fl}$ in particular towards the transition from the I-mode to the H-mode.

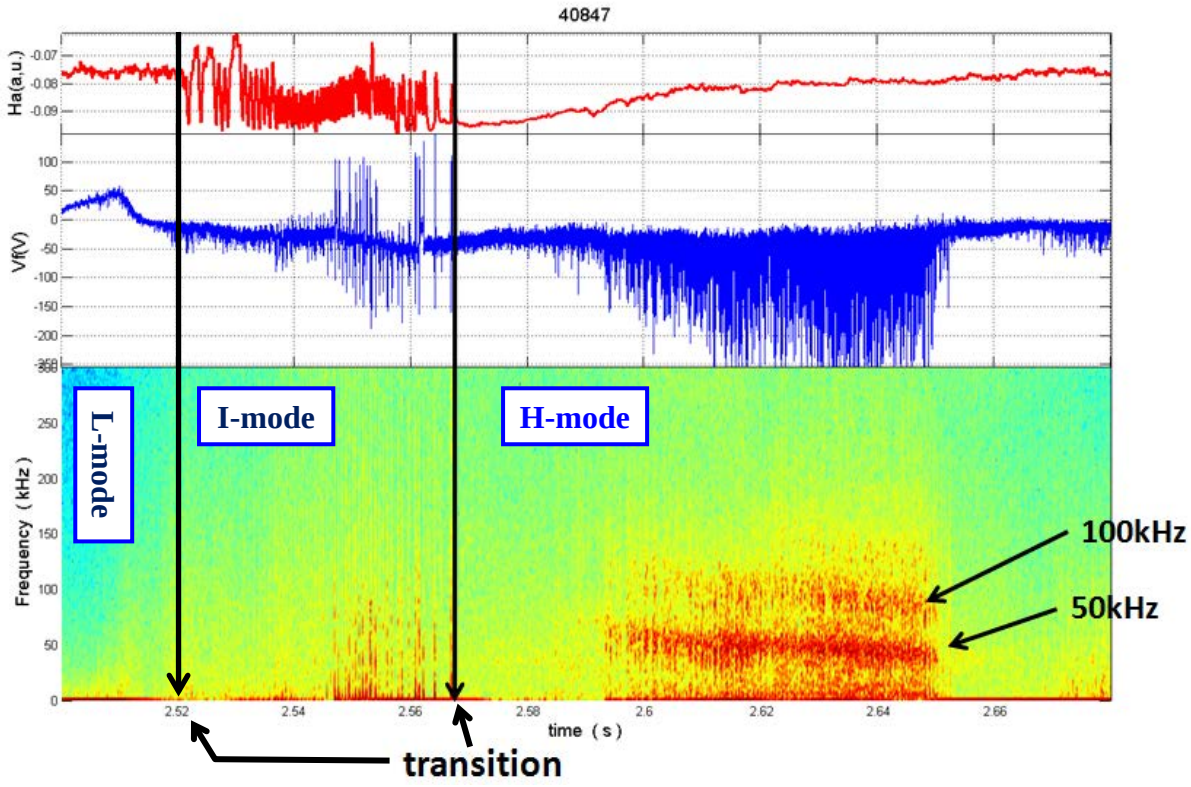


*Fig. 5: From top to bottom: $D_\alpha$-line intensity and floating potential measured with the 3-pin Langmuir probe, and spectrum of floating potential fluctuations. The two black vertical arrows show the transitions from L- to I-mode (Intermediate mode) and from I- to H-mode, respectively.*

At the onset of the H-mode the fluctuations of the $D_\alpha$-line decrease. After about 20 ms strong fluctuations appear in the floating potential. The $V_{fl}$ spectrum shows a first harmonic of 50 kHz, also the second harmonic is clearly visible.

## Acknowledgements:

This work, supported by the European Communities under the Contracts of Associations between EURATOM and ÖAW, IPP, ENEA-RFX and DTU-Fysik, was carried out within the framework of the EFDA. The content of the publication is the sole responsibility of its authors and it does not necessarily represent the views of the Commission or its services. This work was also supported by grant P19901 of the Austrian Science Fund (FWF).

## References

[1] G.S. Xu, V. Naulin, W. Fundamenski, et al., Nucl. Fusion **49** (2009) 092002.

[2] C. Ionita, N. Vianello, H.W. Müller, et al., J. Plasma Fusion Res. Series **8** (2009), 413-418.

[3] R.W. Schrittwieser, C. Ionita, N. Vianello, et al., Contrib. Plasma Phys. **50** (2010), 860-865.

[4] B. Nold, G.D. Conway, T. Happel, et al., Plasma Phys. Control. Fusion **52** (2010) 065005.

[5] F. Mehlmann, S. Costea, V. Naulin, et al., 40th EPS Conference on Plasma Physics (Espoo, Finland, 1-5 July 2013), P