HOLLOW CATHODE ARC ENHANCEMENT IN REACTIVE PVD PROCESSES

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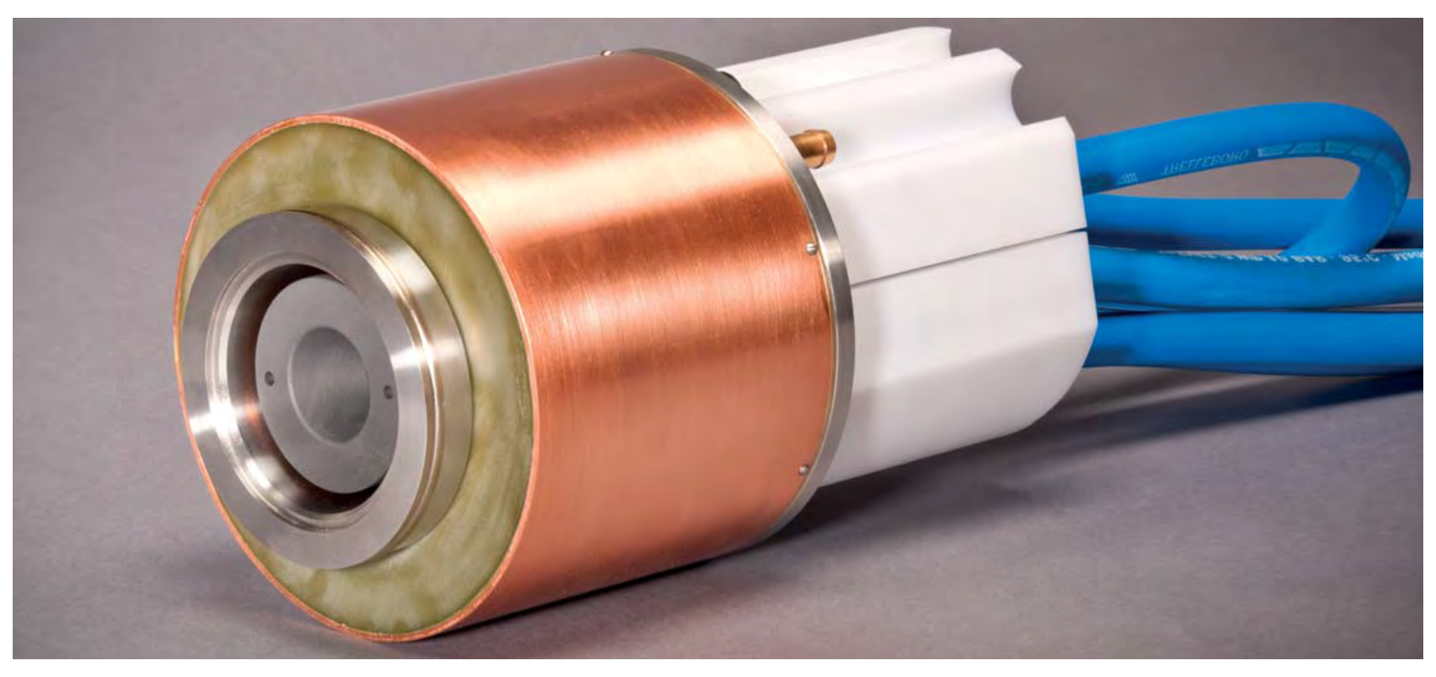
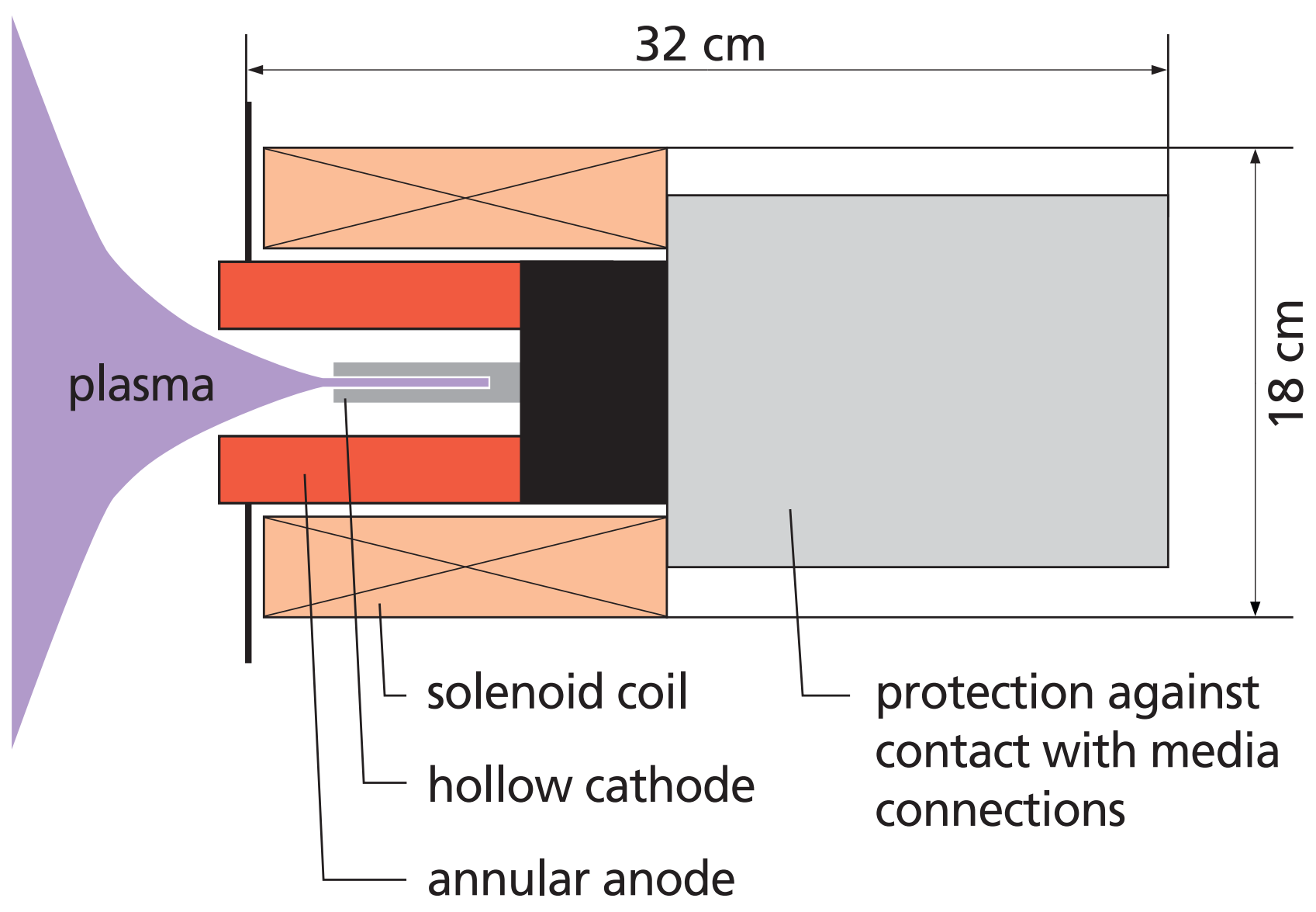
INTRODUCTION

Physical vapor deposition (PVD) processes generally suffer from the restriction that outstanding film quality excludes high rate film growth. Furthermore, in the case of reactive PVD, a sufficient activation of the reactive gas is desirable in order to enhance its reactivity. Hereby, plasma activation of the vapor as well as of the reactive gas is a powerful – and often necessary – tool. The atoms and molecules are dissociated, excited, or ionized in the plasma leading to enhanced particle energy; moreover, their impact energy at the substrate can be tailored by application of substrate bias, e.g. to fulfill optimal crystallization conditions. In this paper, the application of a high power plasma source basing on the hollow cathode arc effect in two plasma-activated PVD processes is presented.



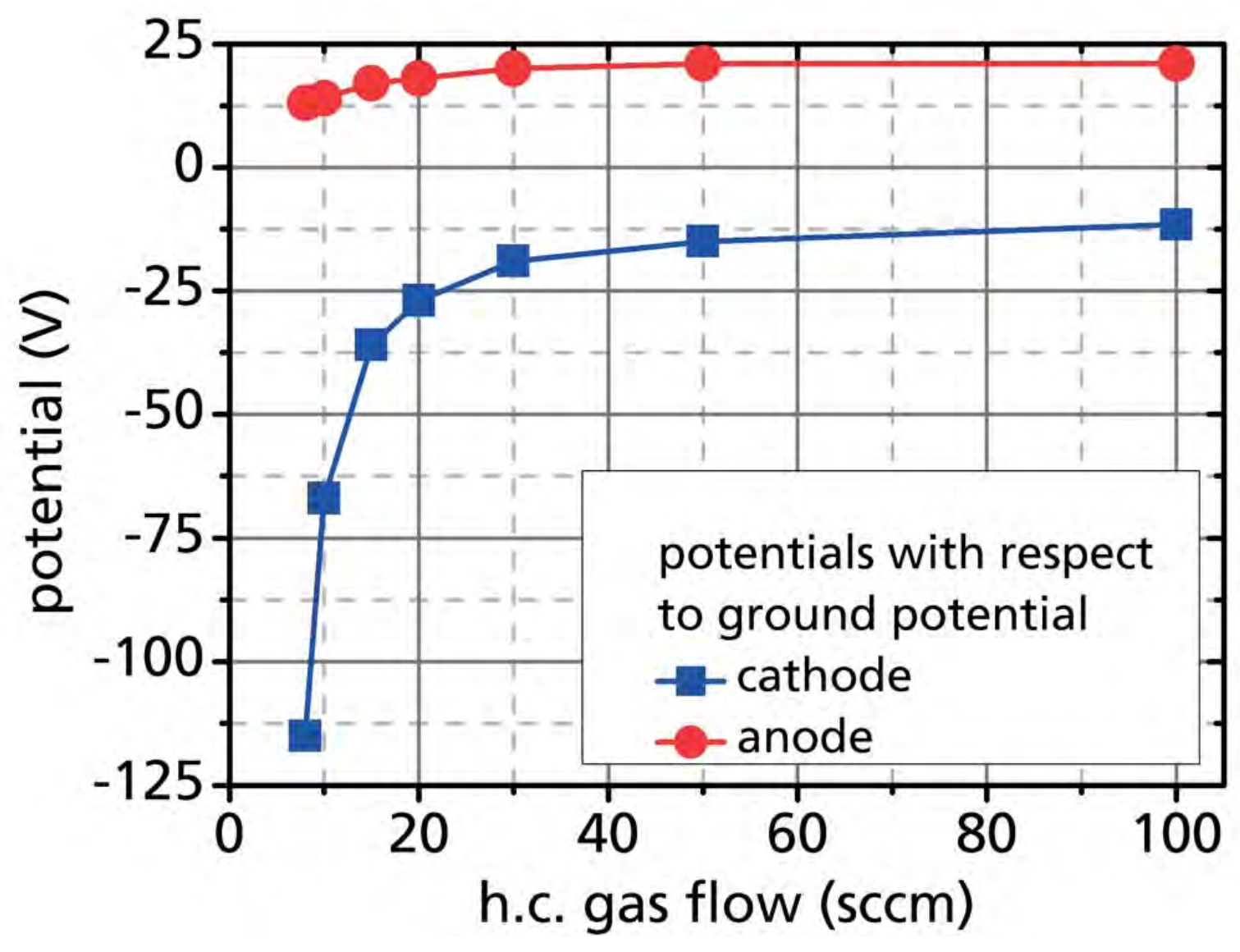
HOLLOW CATHODE ARC PLASMA SOURCE LAVOPLAS

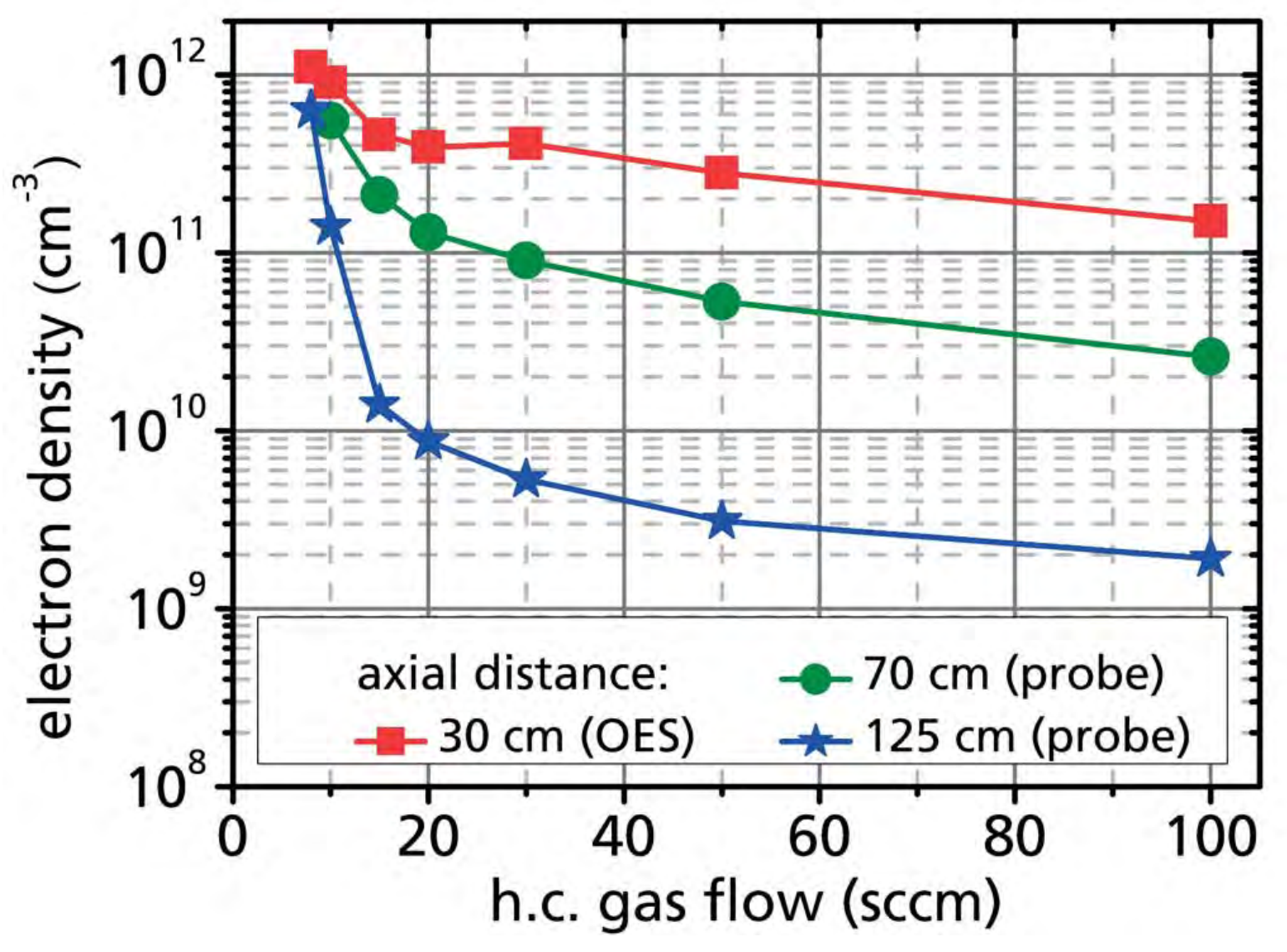


A ring anode and a magnetic field coil are arranged coaxially around the tantalum cathode tube flown through by the working gas argon:

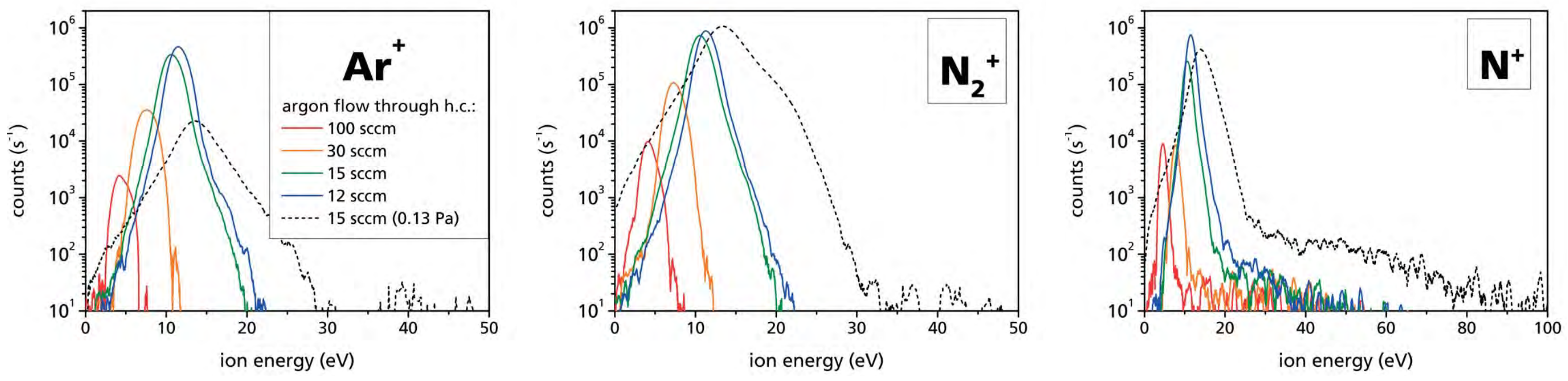
→ diffuse arc discharge within the cathode tube
→ large volume plasma in the process chamber

The magnetic field allows for reduced working gas flow:
→ strongly increased plasma density and range due to larger cathode drop potential and electron energies



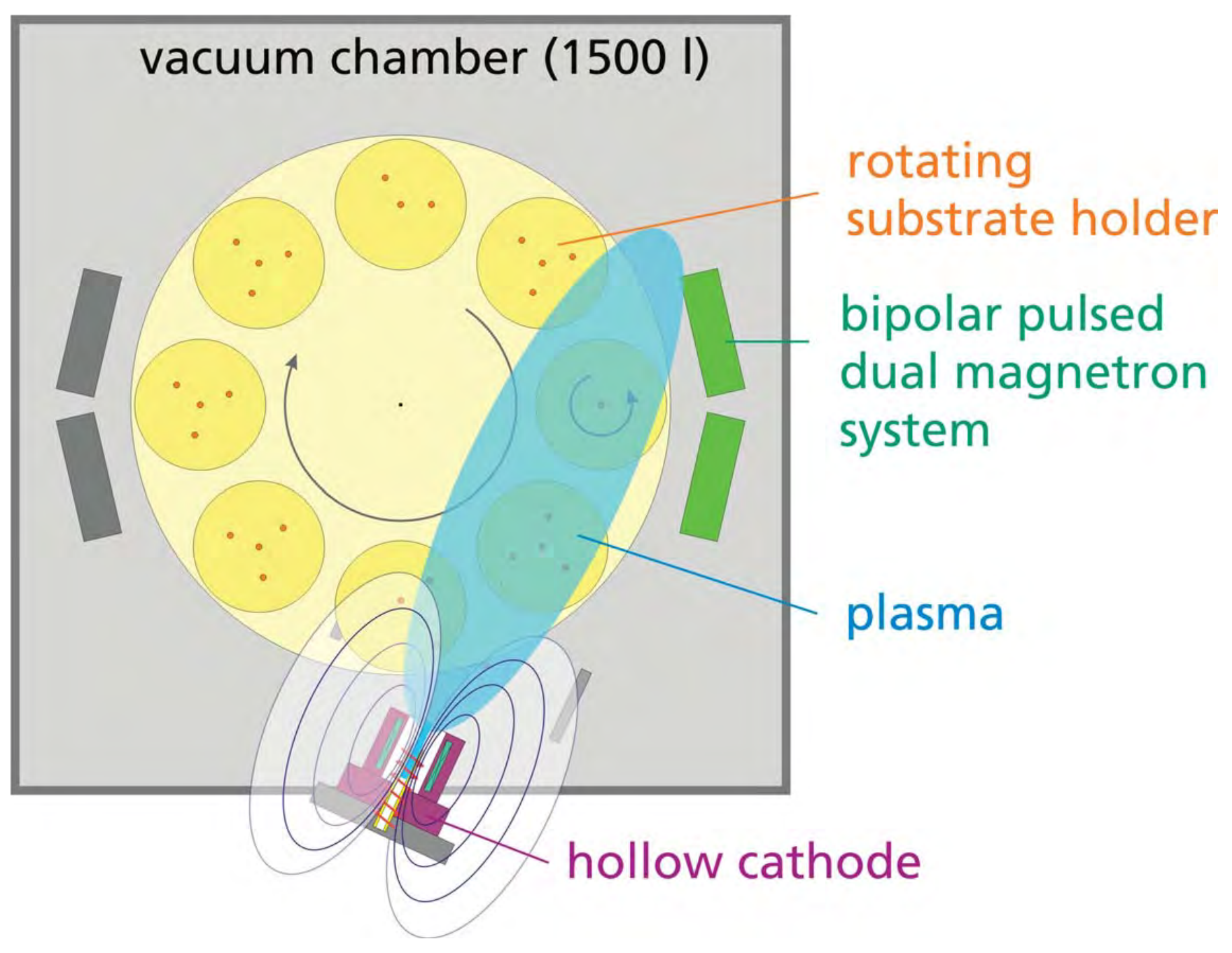


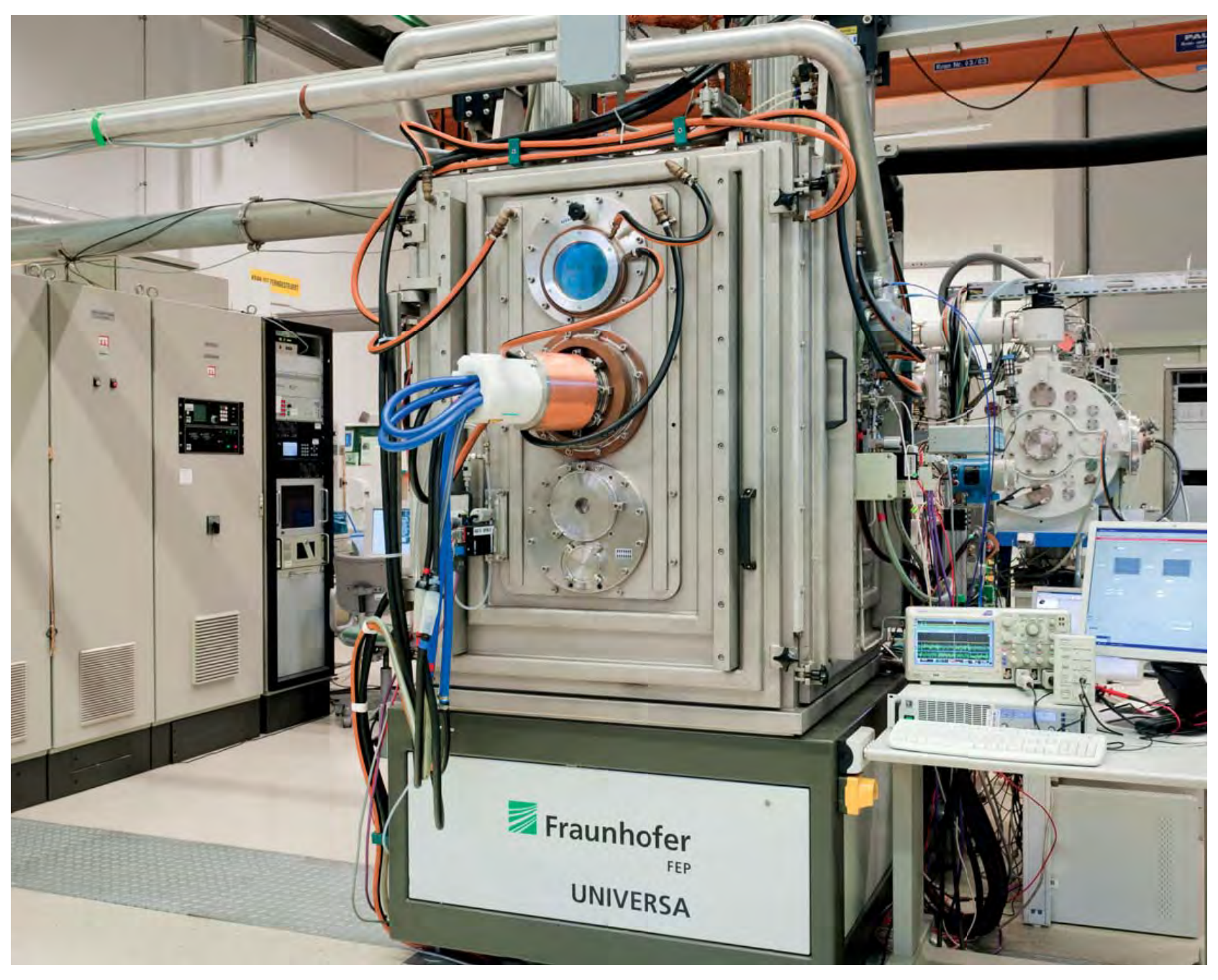
REACTIVE MAGNETRON SPUTTERING OF CHROMIUM NITRIDE



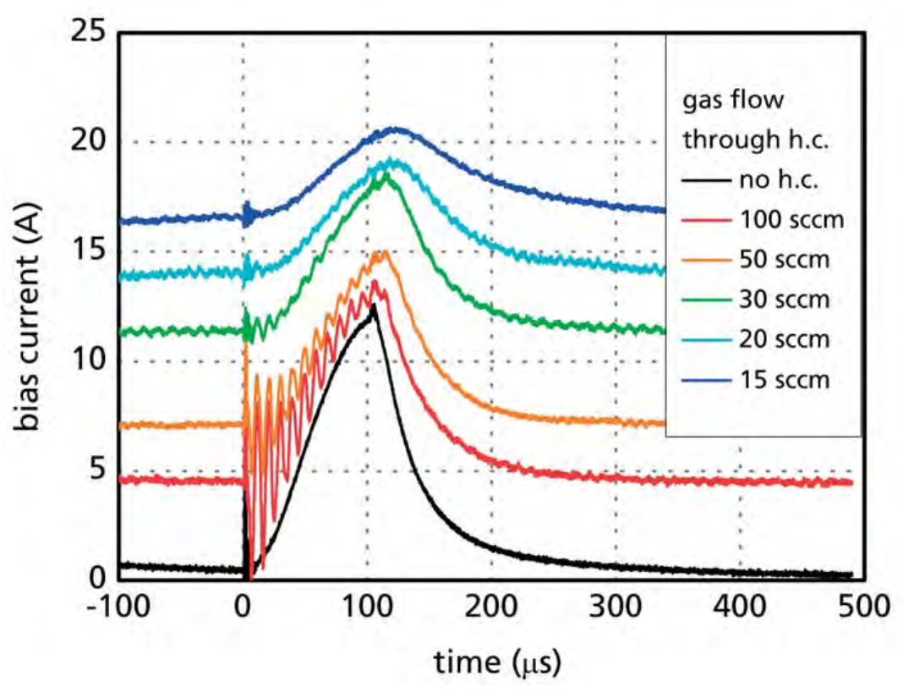
chamber pressure 0.3 Pa, Ar:N_2 1:1, discharge current 100 A, magnetic field 60 mT

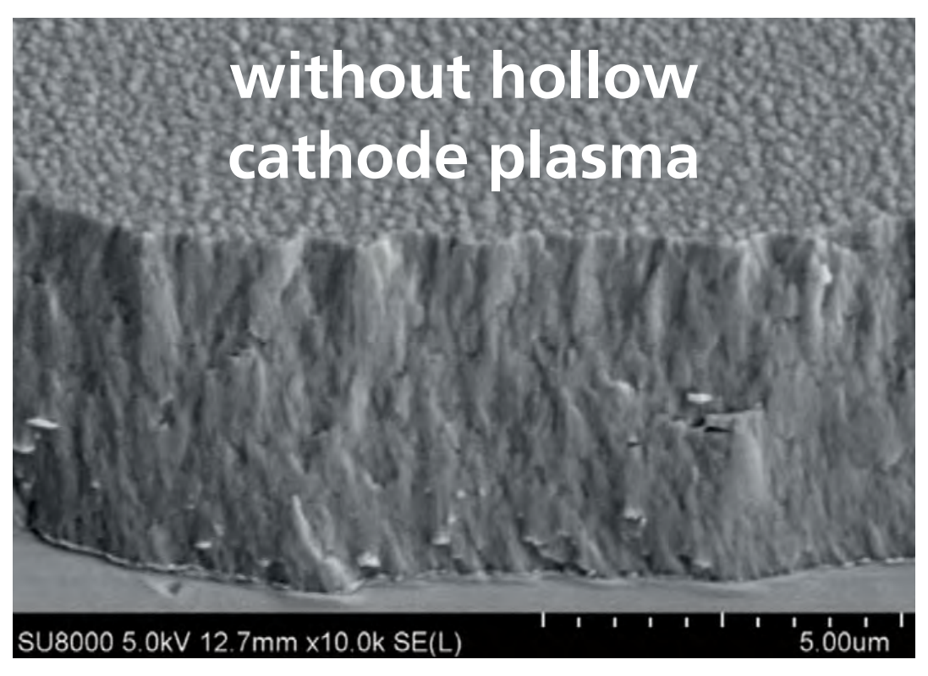
Energy-resolved mass spectrometry at a distance of 130 cm from the hollow cathode orifice shows a strong increase of ionization as well as dissociation rate at reduced argon gas flow rates through the hollow cathode tube. The ion energy distributions consist of a low energy peak (plasma potential: ions from the bulk plasma) and high energy tails (ions generated in the vicinity of the anode at elevated potential).

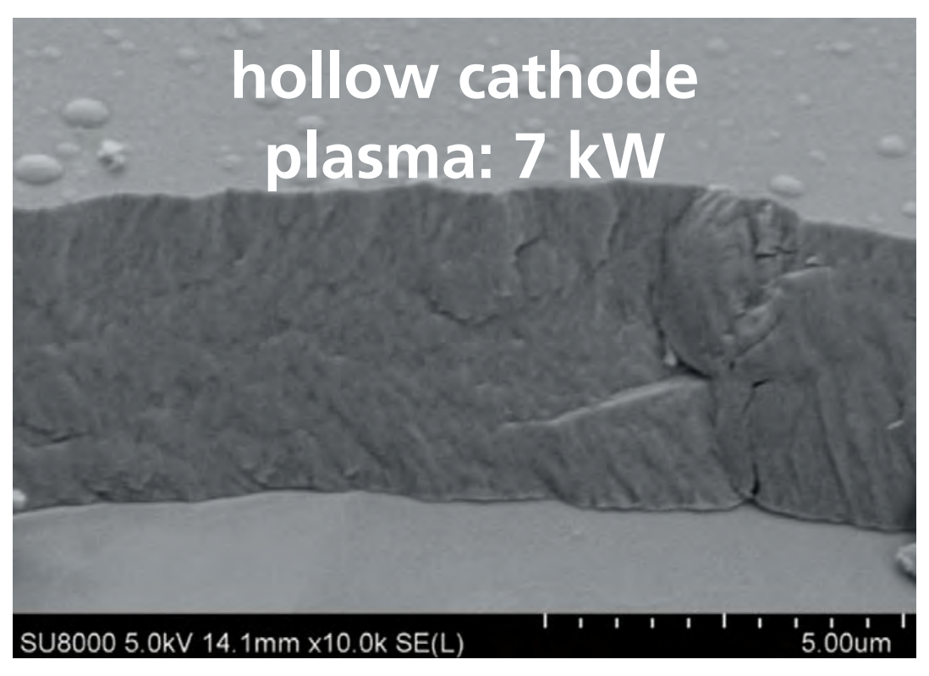




A batch coater with a bipolar pulsed dual magnetron system equipped with chromium targets (50.8 × 12.7 cm²) has been used for reactive deposition of CrN on steel substrates rotating at a distance of 15 cm and 50 cm from the targets and the hollow cathode orifice, respectively.







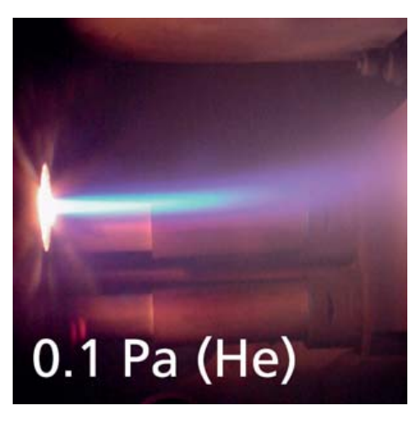
After hollow cathode plasma pre-treatment, the reactive sputtering process (950 V, bipolar pulsing with 1 kHz, 12 ... 15 kW, 0.3 Pa) assisted by the hollow cathode plasma (150 A, 6 ... 14 kW @ 100 ... 15 sccm Ar flow rate) has been performed. The higher the plasma power, the higher the bias current (bias voltage 30 V d.c.) onto the substrates especially during the off-time of the sputtering process *(see left figure)*.

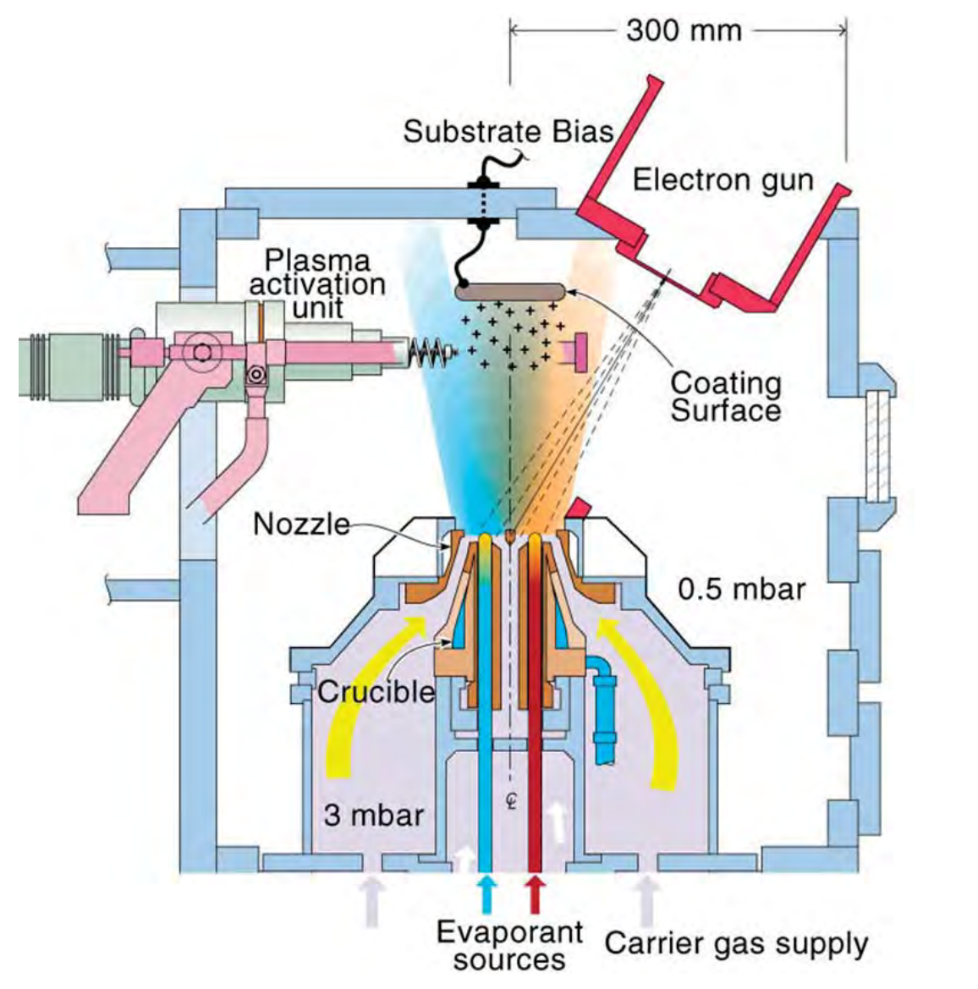
The additional hollow cathode plasma application resulted in a denser microstructure and a smoother surface of the CrN layers *(see SEM pictures)*. The film hardness increased marginally from 23 ... 26 GPa, whereas a remarkably higher nitrogen incorporation (25 → 40 at.-%) was detected by glow discharge optical emission spectrometry. A typical application of CrN are wear-resistant coatings.

REACTIVE DIRECTED VAPOR DEPOSITION (DVD) OF ZIRCONIA

Compared to established electron beam (EB) evaporation, the DVD process (developed by the University of Virginia in cooperation with Fraunhofer FEP) using a supersonic helium jet transporting the vapor onto the substrate and a hollow cathode plasma source ionizing and activating the vapor allows for:

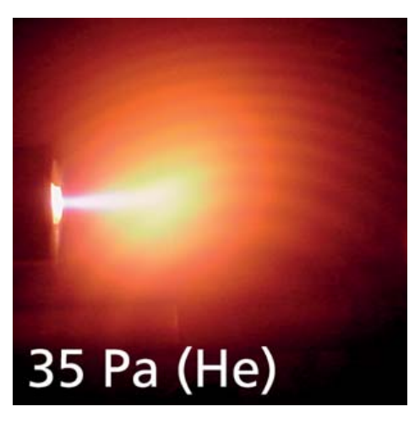
- higher vapor utilization efficiency and focusing, higher deposition rate
- possible non-light-of-sight deposition
- better mixing of vapor and reactive gas species
- enhanced energy of condensing particles and, thus, morphology control

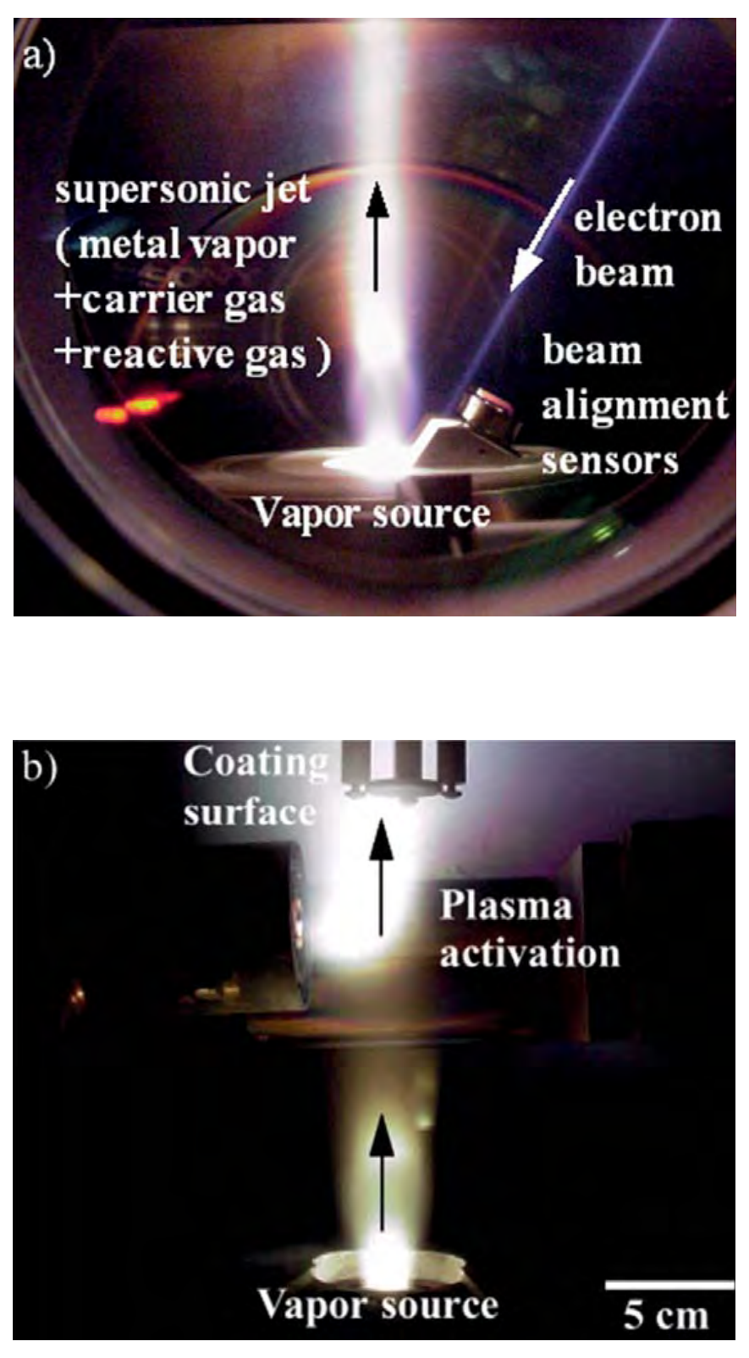




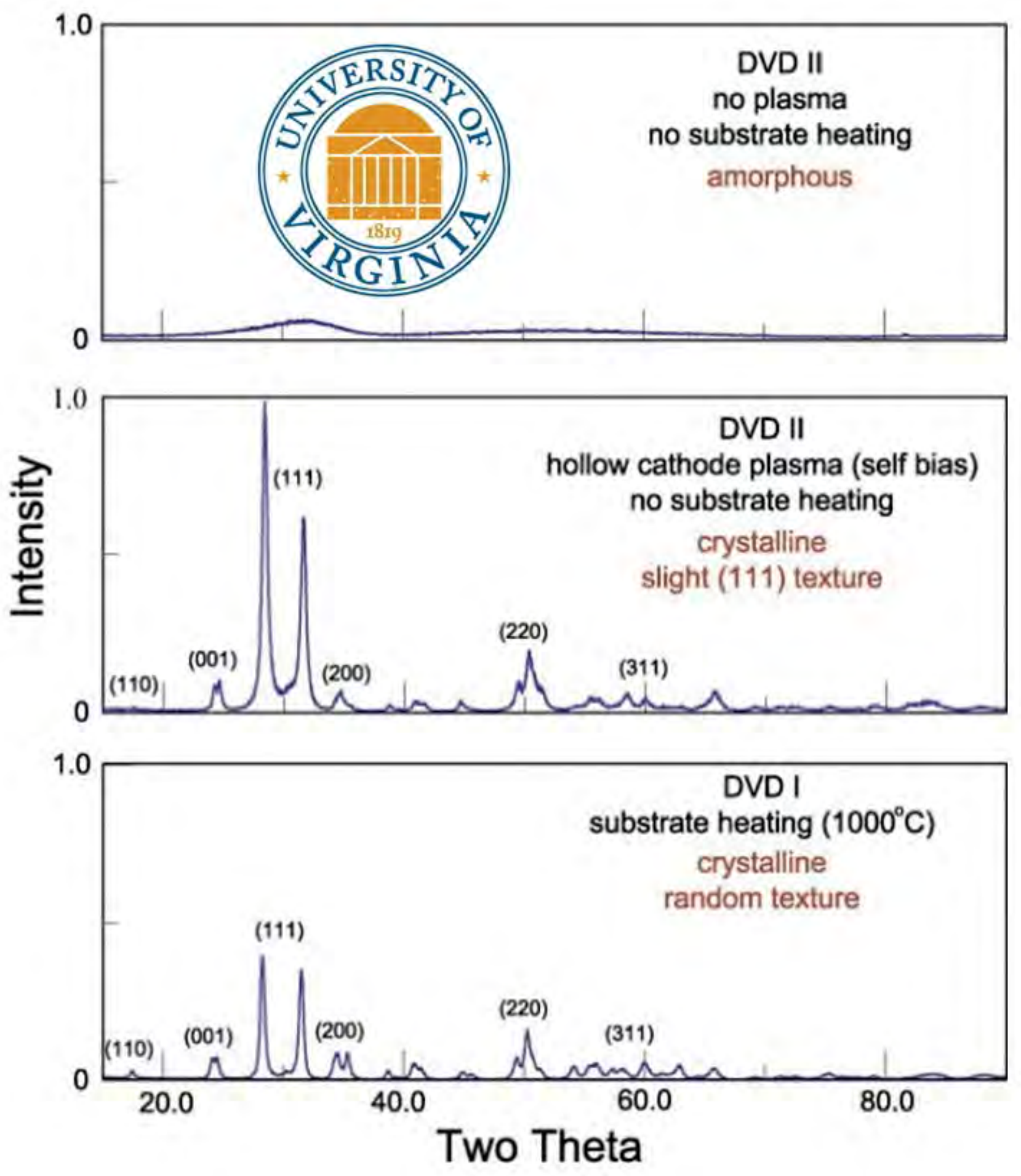
As the hollow cathode arc plasma source can be used at high pressures (35 Pa and more) generating high density plasmas, it is an adequate plasma activation tool for DVD.

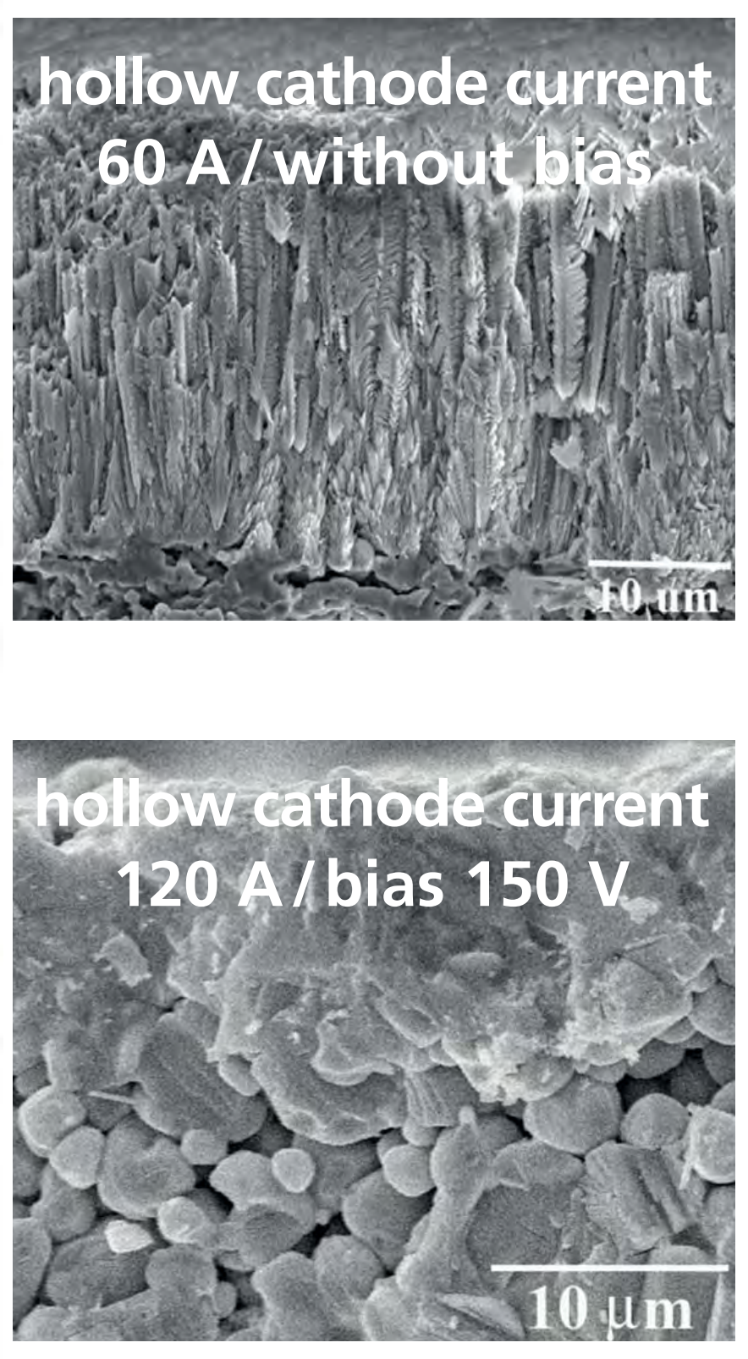
The EB source has been driven with the parameters 70 kV/35 mA/2.5 kW. The enhanced acceleration voltage ensures the beam propagation through the high particle and carrier density. The hollow cathode power was 2 kW. The carrier jet, reactive gas and hollow cathode working gas flow rates were 5 slm (He), 250 sccm (O2) and 50 sccm (Ar), respectively, resulting in a process pressure of ≈ 7 Pa.





Picture of the DVD process without (a) and with (b) hollow cathode plasma activation.





SEM pictures of YSZ after plasma-activated DVD at different hollow cathode plasma currents as well as without and with a substrate bias voltage

As already shown for classical EB evaporation, ionization and excitation of the vapor by plasma activation allows for deposition of dense, smooth layers at high rate. During deposition of ZrO, the hollow cathode plasma activation leads to the growth of crystalline films, and no additional substrate heating is necessary (substrate temperature <400°C, *see XRF spectra for ZrO*; experiments: University of Virginia).

Moreover, in the case of EB-DVD, the plasma source must be placed very close to the vapor stream, and the application of a substrate bias voltage is essential due to the large scattering rate in this high-pressure process. Substrate bias results in a smoother surface topology and in a more uniform microstructure *(see SEM pictures for YSZ)*. Applications of YSZ are thermal protection layers on turbine blades or membrane layers in solid oxide fuel cells.

CONCLUSIONS

The effect of hollow cathode arc plasma activation has been shown on two PVD processes. In the case of magnetron sputtering, the plasma induces ionization and dissociation of the reactive gas for higher reactivity as well as additional ion bombardment of the growing layer resulting in higher nitrogen incorporation and denser microstructure of CrN. For EB-DVD of YSZ, crystalline films without substrate heating as well as a smoother surface topology could be achieved by plasma activation even at high process pressures of around 10 Pa.

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