



Around the Labs

Boronization of W7-AS

In Wendelstein W7-AS the low-Z components oxygen and carbon, and the high-Z metals titanium and iron, released from the titanium carbide limiter and the stainless steel walls are found to be the dominant plasma impurities. After carbonization (the in situ deposition of thin carbon films onto the plasma-facing vessel walls during glow discharges in He and about 30% CH₄ or CD₄), the impurity concentration of the high-Z materials iron and titanium was significantly reduced, but oxygen and carbon still remained, and the recycling coefficient was greater than one. For further reduction of the impurity concentrations and to reduce recycling, boronization has been employed on W7-AS since November 1990. To date we have made three boronization runs on W7-AS.

The use of pure boron layers in W7-AS as a plasma facing material is based on the excellent results obtained from ASDEX. The boronization runs are performed in glow discharges with 10% B₂H₆ (diborane) + 90% He and room temperature vessel walls. The typical glow discharge pressure for boronization is 10⁻² mbar. The operating conditions for the three electrodes, which are toroidally separated by about 120°, are about 3 A and 600 V. For safe handling of the diborane, which is both toxic and explosive, the gas mixture is fed from a pressure bottle located in a special gas case to five gas inlets via a low-pressure tube system of coaxial design. In conjunction with the gas inlets, an exhaust system was installed, composed of one of the standard turbomolecular pumps of W7-AS, backed by a Roots blower and a thermal decomposer ($\approx 750^\circ\text{C}$), followed by a special chemical pump and a KMnO₄ filter. Diborane in the exhaust system is completely decomposed in the filters into harmless products. The gas feed and the

exhaust system are continuously monitored for diborane during boronization runs.

During boronizations a removable probe is located at the vessel wall. An oscillator crystal mounted on the probe allows an on-line determination of the layer growth. Local surface analysis of the deposited layers yielded inhomogeneous thicknesses over the probe diameter (140 mm) of 300 to 800 Å. Surface analysis of the probe yielded a mixture of about 60% boron, 30% hydrogen, and 10% carbon. The long-term behavior of the layers will be investigated by probes distributed poloidally and toroidally inside the vacuum vessel.

Boronization has resulted in a considerable reduction of impurities and reduced the recycling coefficient (to < 1) during plasma discharges. Levels of oxygen and carbon (the dominant low-Z impurities) were lower than in experiments with metallic walls. Oxygen, for example, was reduced by a factor of more than ten as observed by spectroscopy. The high-Z components titanium and iron were significantly reduced, but returned to high values after some shots during which the boron film was eroded from the limiters. Titanium actually increased by a factor of about two above the pre-boronization value, whereas iron remained lower by a factor of about two. This observation is explained by the high edge temperatures after boronization which are due to reduced radiation losses in the plasma edge region. Consequently the limiter load was observed to decrease by a factor of three after boronization, corresponding to higher impurity release from the limiters. These observations also support the assumption that part of the iron flux originates from iron deposited on the limiters by glow discharge conditioning. However, the beneficial effects on the oxygen and carbon concentrations and on the recycling coefficient remained over a long period of time, even in the case of accidental venting.

Boronization provides significantly improved plasma conditions. After fresh boronization of W7-AS the operation mode for 80-GHz ECR-heated plasma discharges at low power levels $P_N < 200$ kW was extended by a factor of two with respect to density and energy (rota-

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tional transform $\tau = 0.34$, $B_0 = 2.57$ T). It was possible to operate near the cutoff density, and a significant increase of the energy replacement time (up to 40 ms) was achieved. With boronized walls, discharges at stationary densities with constant gas influx were obtained (recycling coefficient < 1).

The layers were further tested in NBI-heated discharges. For example, with two H^0 beam lines, and an average density of $1.5 \times 10^{20} \text{ m}^{-3}$, the energy content was improved to 23 kJ without optimization arrangements. With four sources (absorbed power of 1.1 MW) record values in energy content, up to 33 kJ ($\beta = 0.7\%$ at 2.5 T) at an average density of $3 \times 10^{20} \text{ m}^{-3}$, were observed. The energy confinement time was estimated to be 30 ms. For boronized wall conditions the fraction of radiated power compared with the input power $P_{\text{rad}}/P_{\text{tot}}$ was about 35%. However, some NBI-heated discharges showed short-term breaks in plasma energy and temperature correlated with an increase of the titanium flux, but energy and temperature increased again with a simultaneous decrease of the radiation to its former level.

Boronization seems to be most promising for further improvements. The reduction of oxygen and carbon is obviously durable and allows significantly improved plasma conditions over a long period of time. To avoid metallic impurities in the discharges we plan to replace all titanium carbide vessel components by boron-doped graphite material. In addition, we envision careful protection by carbon tiles of those stainless steel components acting as secondary limiters.

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News from CHS

Experiments on the perturbation field have continued since the previous Stellarator News. Magnetic field mapping experiments with and without the perturbation field were done at the end of last year. The perturbation field is applied in almost steady state. The experimental island width and phase agree well with the computational results. It is expected that $m/n = 2/1$ islands with a full width of several to 10 cm are formed in the heating experiments with a magnetic field of 1 T. Magnetic surfaces near the edge are not destroyed so much, although we have not quantitatively estimated their ergodization.

The substantial decrease in the diamagnetic signal of ECH plasmas with the perturbation cannot be explained with electron temperature and density profiles (Thomson scattering) or the ion temperature profile (CXRS). To eliminate ambiguity in Thomson scattering measurements near the edge, three types of material limiters were introduced to scrape the edge plasma because the ECH plasma has an electron density profile with a fairly strong hollowness. These limiters are the Nagoya type-III antenna from the outboard and low-field side, a TEC-1 graphite limiter from the inboard and low-field side, and a molybdenum limiter from the high-field side. All are located at toroidal positions where the plasma cross section is horizontally elongated. The TEC-1 limiter had no effect because it could reach only to the outermost magnetic surface. When the other two limiters (antenna and molybdenum limiter) were inserted inside the outermost magnetic surface, diamagnetic signals did not decrease with the perturbation field. This is consistent with the profile measurements showing no essential change. However, some phenomena remain to be clarified.

Toroidal plasma rotation has been measured as a function of electron density for some magnetic axis positions. When the axis is shifted in, where the helical ripple vanishes in the center, the rotation speed shows a weak dependence on the electron density. On the other hand, when the axis is shifted out, the rotation speed shows a nearly $1/n_e$ dependence because of the neoclassical effect due to the large helical ripple in the center. These observations can be explained with both neoclassical and anomalous viscosities.

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Status of ATF

Permission was obtained to operate ATF with a substantially reduced scope for the remainder of the fiscal year. The proposed program is strongly focused on studies of fluctuations at low collisionality and effects of electric field on transport. The concentration will be on ECH-only plasmas, mostly at 1 T. Essential diagnostics are the heavy ion beam probe (HIBP, in collaboration with Rensselaer Polytechnic Institute) and 2-mm microwave scattering, the latter in fabrication by the L-2 group in Moscow, USSR. Perturbative transport studies will be made using error-field coils, biased limiters, pellet injection, ECH power modulation, etc. These experiments will make maximum use of the external control of the magnetic configuration with a pulse length up to 20 s. Modest upgrades of power supplies and ECH for a pulse length longer than 20 s will be made in collaboration with the LHD group, Nagoya, Japan.

The ATF experiment restarted on January 25 after completion of an in situ neutral beam power measurement. Studies of ECH power deposition and performance optimization were made by scanning the field intensity, polarization direction, and plasma density. We also tried ECH power modulation experiments, modulating with 25% peak-to-peak square waves of different frequencies. The amplitude and phase shift of local temperature measured from electron cyclotron emission (ECE) carry information about power deposition and local heat diffusivity.

The HIBP has extended the density fluctuation measurements, previously carried out with the fast reciprocating Langmuir probe (at normalized radius $\rho > 0.95$) and the microwave reflectometer (at $\rho > 0.8$), down to about $\rho = 0.3$. A nearly constant fluctuation level \tilde{n}/n of the order of 1% was observed. Initial electric potential measurements in an ECH discharge (with $T_e(0) = 1.2$ keV at $\bar{n}_e = 0.6 \times 10^{19} \text{ m}^{-3}$) showed a relatively flat positive potential of about 500 V in the core with a sharp drop toward the plasma edge. An interesting observation is a change of the edge potential when the limiter was biased (with positive potential of 120 V). A spectroscopic Doppler measurement observed poloidal plasma rotation $V(\theta)$ of about 3×10^3 m/s at about 2 cm from the edge and is being correlated with potential measurements made using the HIBP and Langmuir probe.

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IPP Garching Stellarator Contributions at the 18th European Conference, Berlin 1991

A rather large number of stellarator papers was submitted by IPP Garching to the forthcoming 18th European Conference on Controlled Fusion and Plasma Physics, to be held at the Kongreß Halle in Berlin from 3 to 7 June 1991. In the following, the titles and leading authors are listed, along with a short abstract of the invited paper.

Optimum confinement in the Wendelstein 7-AS stellarator – A. Weller for the W 7-AS Team

Optimum confinement properties are found in Wendelstein W7-AS (low shear modular stellarator, $R = 2$ m, $a \approx 17$ cm), if low-order rational values of the rotational transform can be excluded from the plasma cross section or if sufficient shear is introduced by internal currents. The effective heating of net current-free plasmas by ECH (power up to 1 MW, 70 GHz) and neutral beam injection (NBI, power up to 1.5 MW, 40 kV) involves different plasma parameter and transport regimes. The characteristics of the neutral particle, plasma ion, and impurity transport are described and related to the specific heat and particle sources, the magnetic configuration, and the plasma stability. Quasi-stationary plasmas are generally produced by ECRH, whereas density control is a severe problem during NBI due to beam fueling and improving confinement. This effect also leads to significant radiation losses, which have initiated different kinds of impurity and particle control scenarios (carbonization, boronization, and ECH-induced particle pump-out). The investigations comprise particle transport modeling using the DEGAS code based on H_α measurements at relevant locations around the torus and impurity transport studies by laser blow-off experiments. The determination of the impurity transport coefficients of the tracer impurities by the transport code simulations also permits analysis of the intrinsic impurity content.

Thermal diffusivity from heat wave propagation in W7-AS – H.J. Hartfuß

Ion heat conductivity, radial electric fields and cx-losses in the W7-AS stellarator – J. Junker

Particle transport and recycling studies on the W7-AS stellarator – F. Sardei

Fluctuation measurements in the 10 kHz range on the W7-AS stellarator – R. Jaenicke

MHD activity driven by NBI in the W7-AS stellarator – A. Lazaros

Impurity behaviour in W7-AS plasmas under different wall conditions – R. Burhenn

Plasma edge studies at the W7-AS stellarator before and after wall boronization – P. Grigull

Simulation of the influence of coherent and random density fluctuations on the propagation of ECRH-beams in the W7-AS stellarator – M. Tutter

Collisionless alpha particle confinement in stellarators – J. Nührenberg

Optimization of coils for divertor experimentation in W7-X – P. Merkel

Structure of magnetic field line diversion in helias configurations – E. Strumberger

Optimization of analytic stellarator fields by using mapping methods – F. Hermegger

Neoclassical transport in stellarators – a comparison of conventional stellarator/torsatrons with the advanced stellarator W7X – C. Beidler

On natural islands and the edge structure of the W7-X stellarator – F. Rau

On the existence and uniqueness of dissipative plasma equilibria in a toroidal domain – M. Spada

The role of Pfirsch-Schlüter currents in plasma equilibrium, stability and transport – H. Wobig

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