AIT-PIDにおける重水素プラズマの生成とそのPWI研究への応用

（１）　AIT-PIDにおける高熱流重水素プラズマの生成

（２）　重水素プラズマ－タングステン系における熱伝達係数評価

（３）　重水素プラズマ中におけるタングステンへの熱パルスの効果

（４）　タングステンへの重水素プラズマの重照射の準備

髙村　秀一

愛知工業大学工学部電気学科

謝辞:　愛工大プラズマ研究室卒研生、大野教授（名大）

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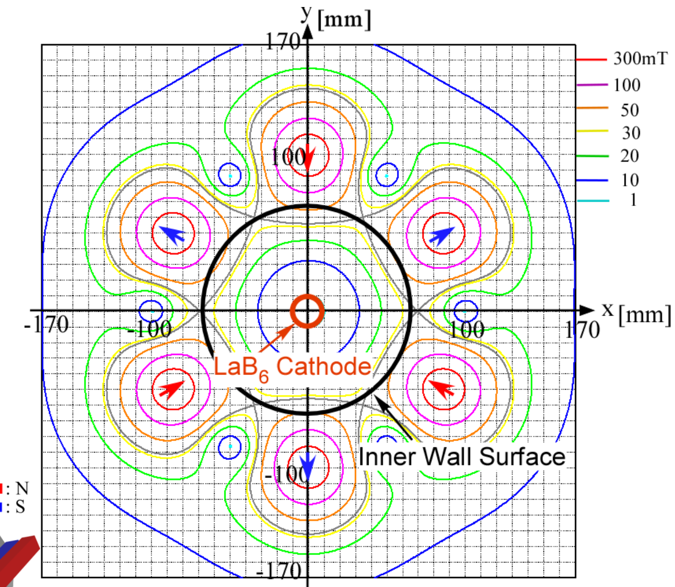
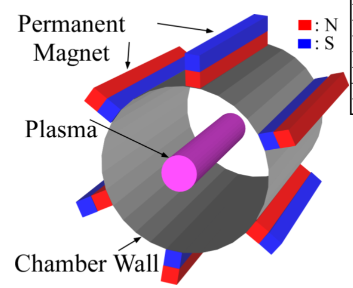
Magnetic Structure in AIT-PID

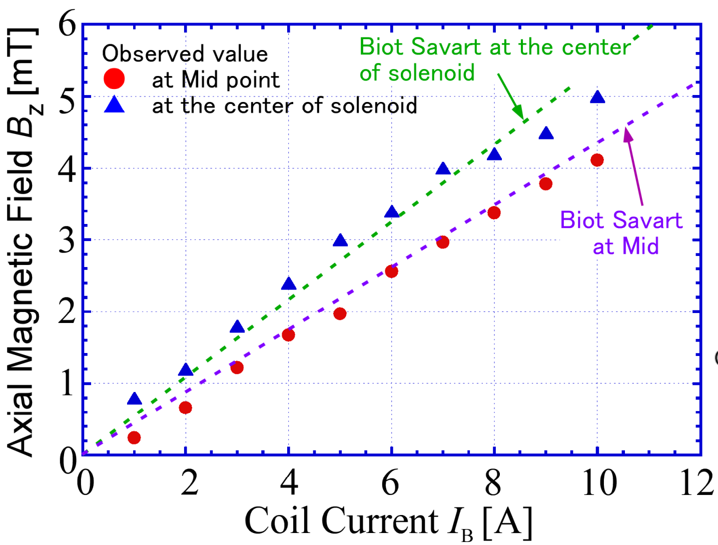
Usually a **strong magnetic field** more than roughly 0.1T has been employed in linear plasma devices for the radial confinement of produced plasma.
The consumed electric power for energizing the magnetic coils is sometimes very large.

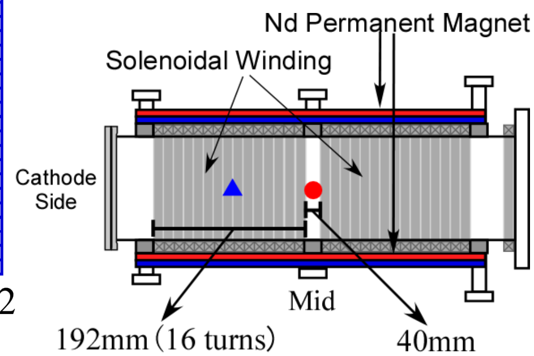
Not only a contribution to power saving compactness, but also a favorable effect on the maintenance of directly heated LaB_6 ceramic cathode have been obtained by a very weak Lorentz stress on LaB_6 solenoid.

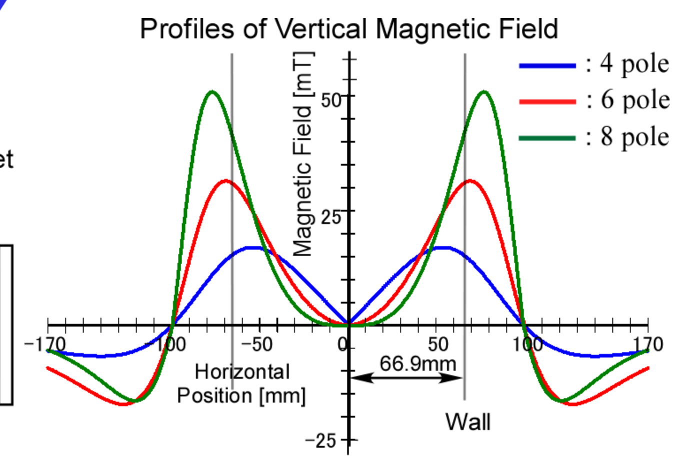




Additional Weak Axial Magnetic Field

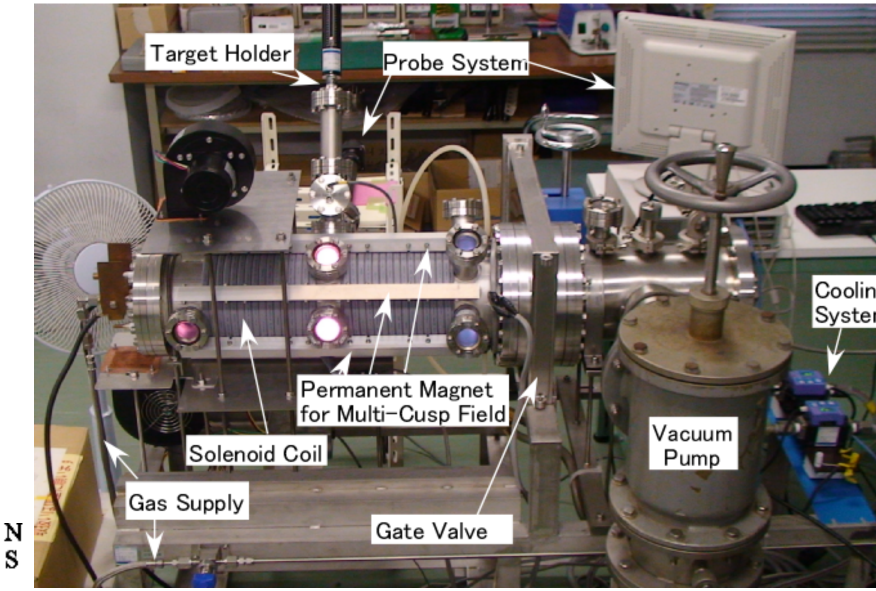


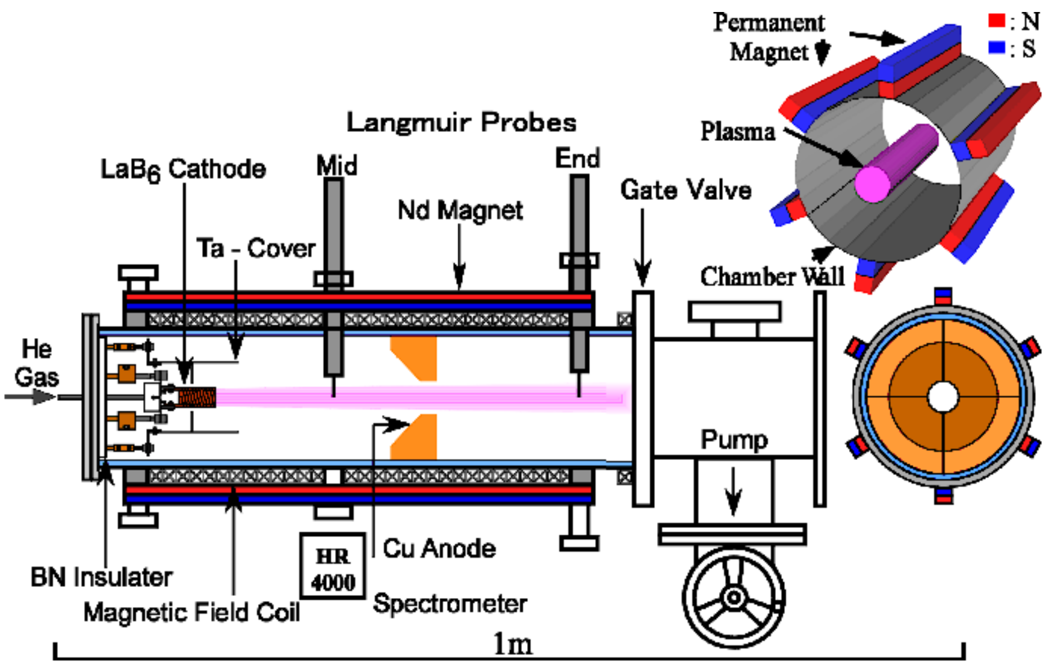


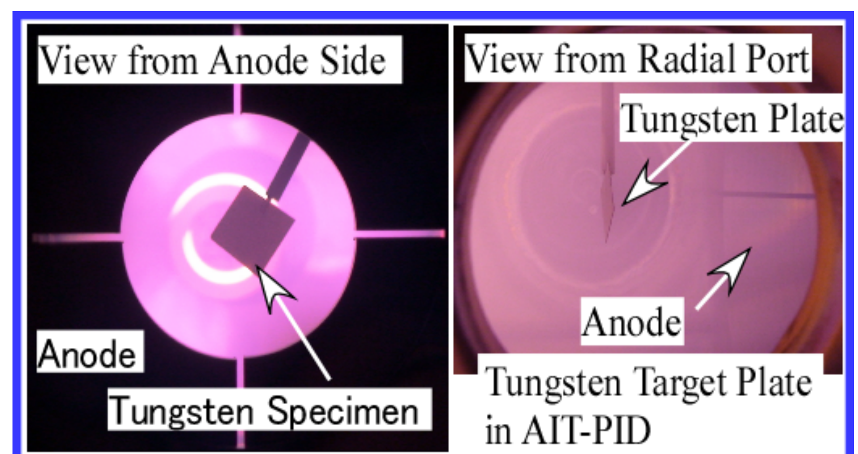


Characterization of AIT-PID Plasmas

Plasma Density > 1×10^{18} m^{-3}
Electron Temperature : 4 eV
with 10% Hot Component (40 eV)
Floating Voltage : ~ 40 V
Plasma Potential : ~ 5 V
Ion Flux : 1×10^{22} m^{-2}s^{-1}



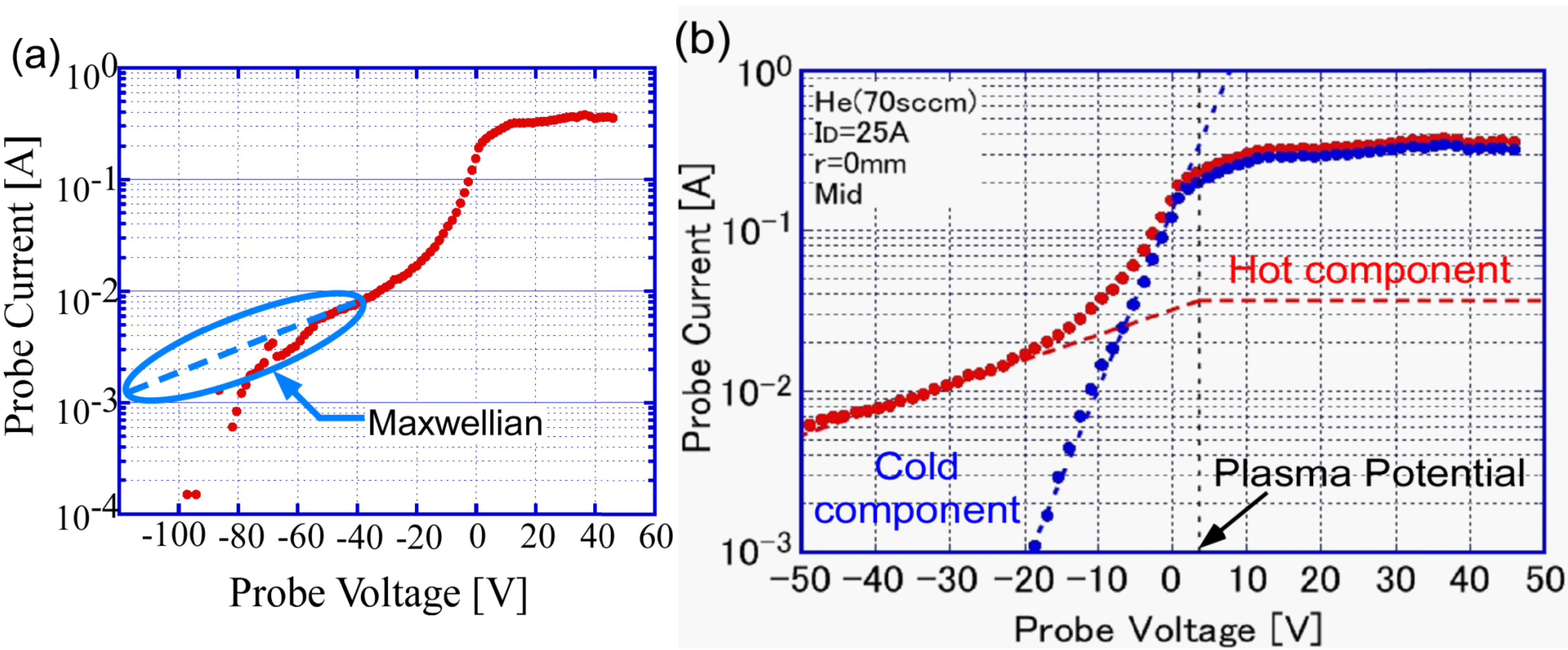




Hot Electrons

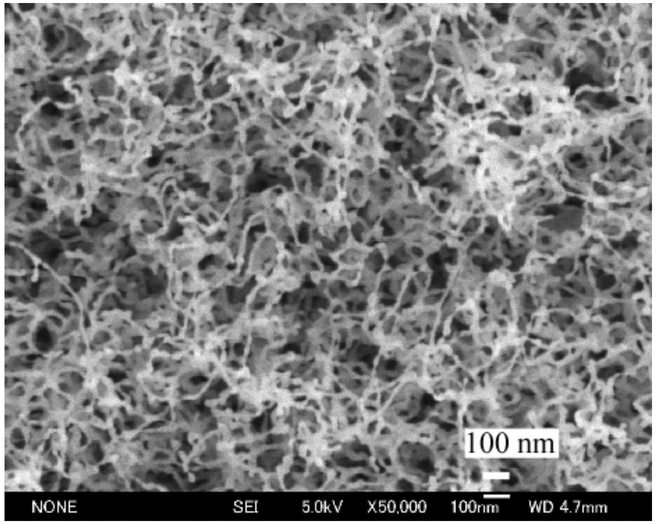
- AIT-PID contains hot electron component:
  10 % with T_{eh} ~ 40 eV, while T_{ec} ~ 4 eV.

- The energy distribution is not a complete Maxwellian,
  but has a cut around the discharge voltage.



Nanostructure on Tungsten Surface

物理学会誌
９月号　解説



Finding of Nanostructure Formation
on Tungsten Surface
at 2006

Plasma and Fusion Research: Rapid Communications Volume 1, 051 (2006)

Formation of Nanostructured Tungsten with Arborescent Shape due to Helium Plasma Irradiation

Shuichi TAKAMURA, Noriyasu OHNO[1], Dai NISHIJIMA[a] and Shin KAJITA

Department of Energy Engineering and Science, Graduate School of Engineering, Nagoya University, Nagoya 464-8603, Japan

[1]*EcoTopia Science Institute, Nagoya University, Nagoya 464-8603, Japan*

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Deeply nanostructured tungsten with an arborescent shape was found for the first time to be formed on tungsten-coated graphite by a high-flux helium plasma irradiation at surface temperatures of 1250 and 1600 K, an incident ion energy of 12 eV (well below the physical sputtering threshold) and a helium ion fluence of 3.5×10^{27} m^{-2}.

Keywords: plasma-material interaction, nanostructured tungsten, helium bombardment

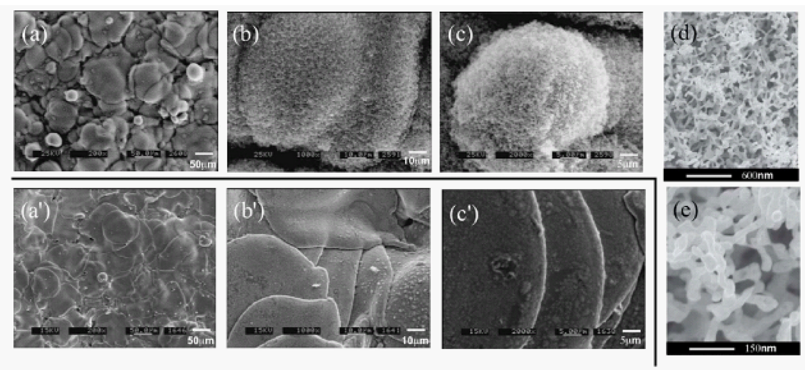
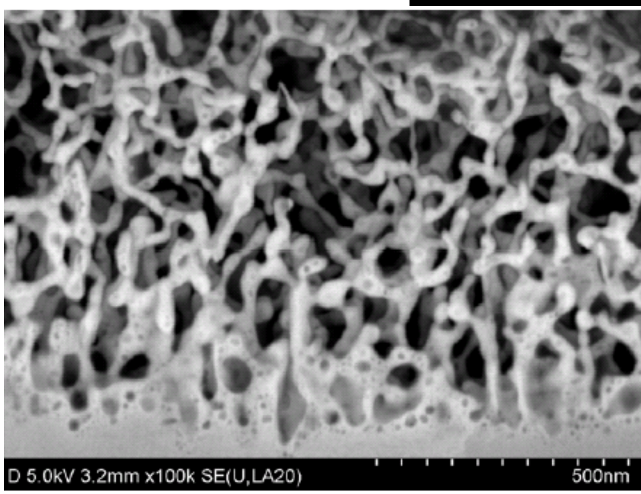
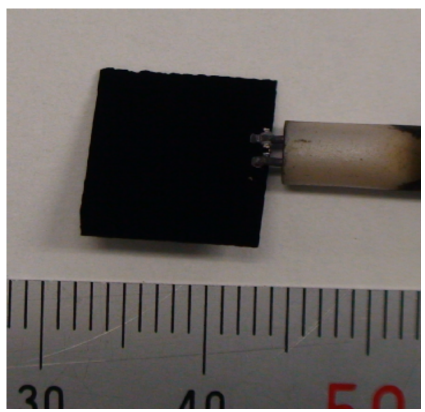


Fig. 1 (a)~(c): SEM photographs of W-C surface after and (a')~(c') before helium plasma irradiation at a surface temperature of 1250 K, a fluence of 3.5×10^{27} m^{-2} and an ion incident energy of 12 eV. (d) and (e): photographs taken by FE-SEM with a high spatial resolution. The line of sight is normal to the samples.





S. Takamura et al.:

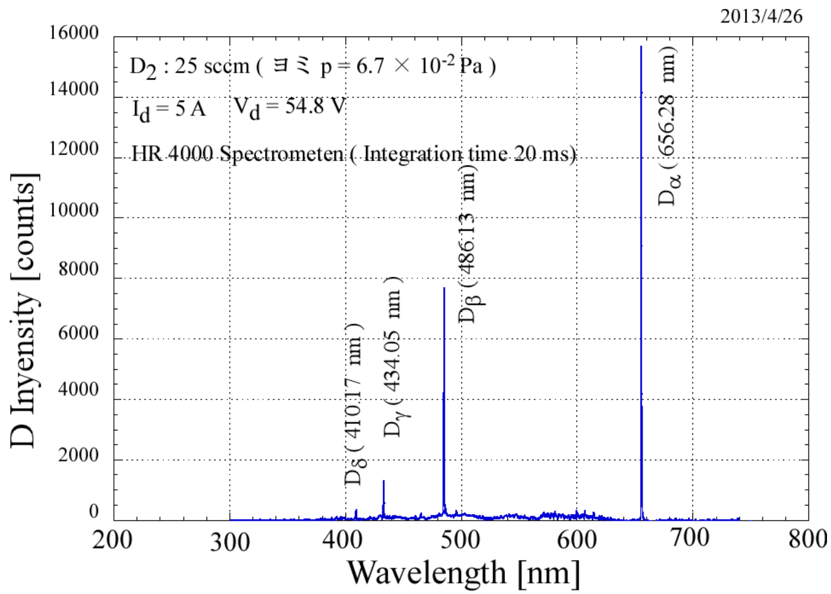
(1) Plasma Fusion Res. **5** (2010) 039 : Deepening of Floating Potential

(2) Proc. 38th EPS Conf. on Plasma Phys. (2011) O1.302: Outstanding Properties

(3) J. Nucl. Mater. **415** (2011) S100 : Effect of Temperature Excursion; J. Nucl. Mater. 438 (2013) S814 : Temp. Measurement

(4) Plasma Fusion Res. **6** (2011) 1202005; Plasma Sci. & Technol. **15** (2013) 161 : Recovery of W Surface

重水素プラズマ生成



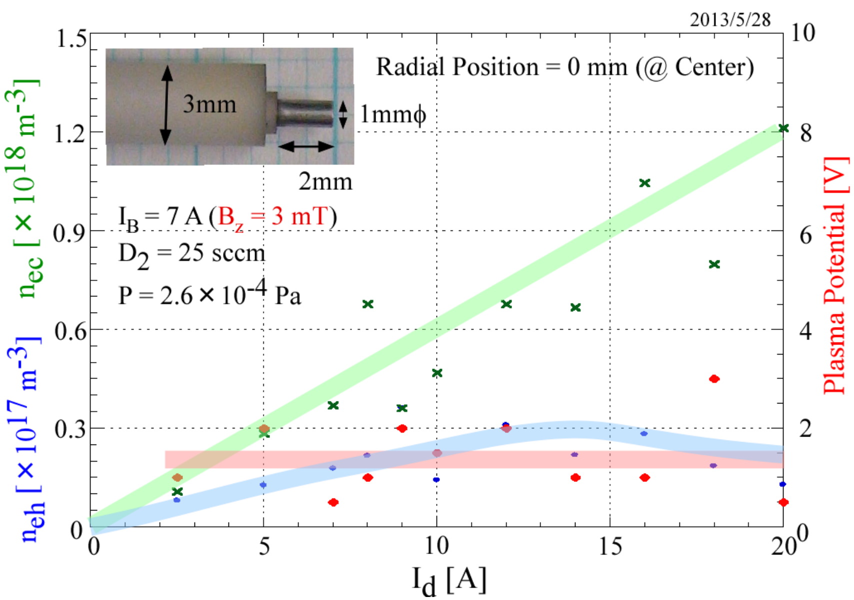
Dプラズマ

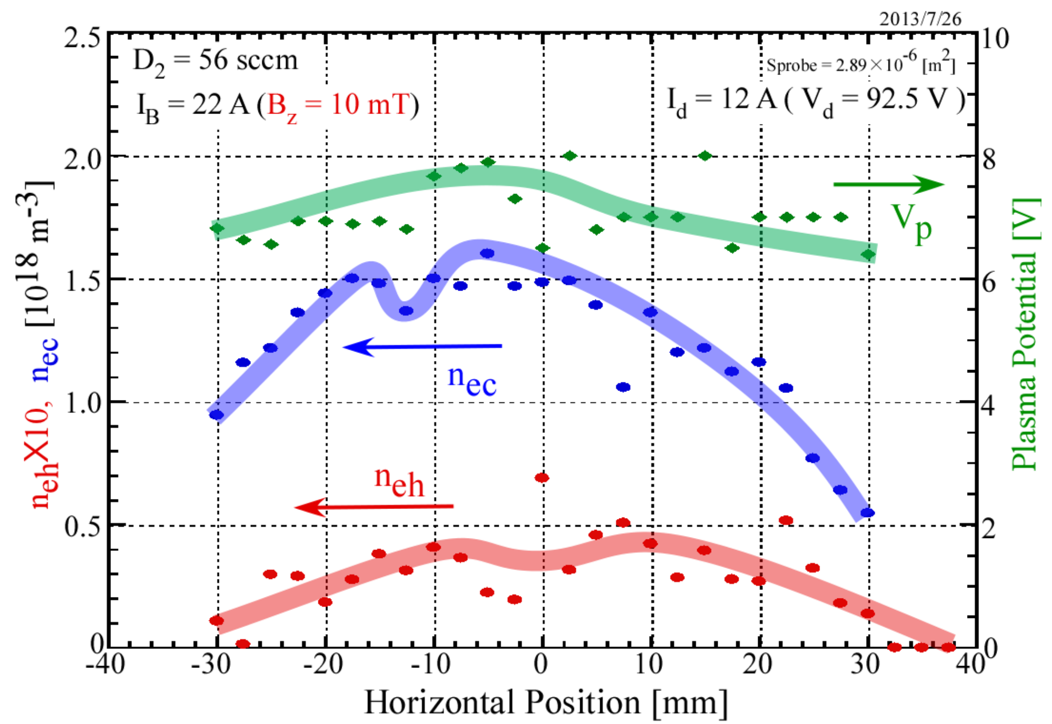
密度 : $\geq 1\times10^{18}$ m^{-3}

Tec : ~ 3 eV; Teh : 20 ~30 eV

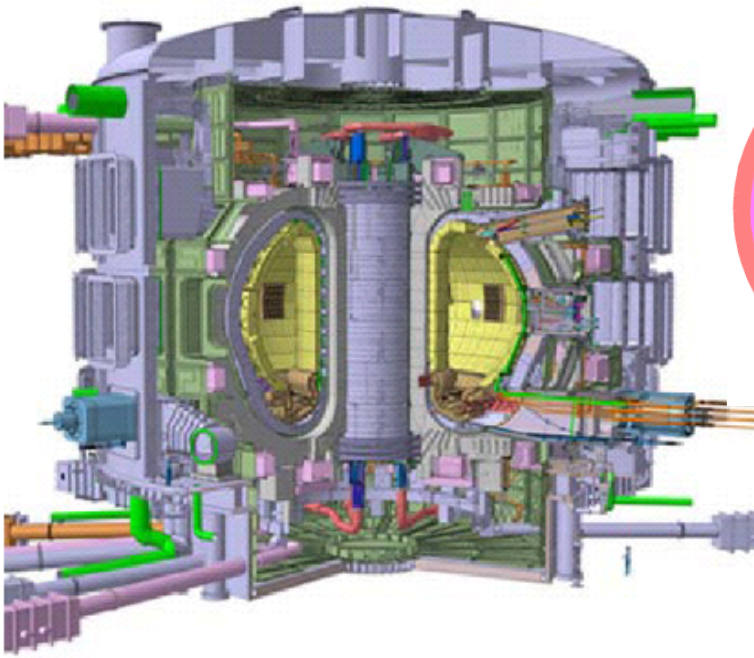
α (abundance) ≲ 5 %

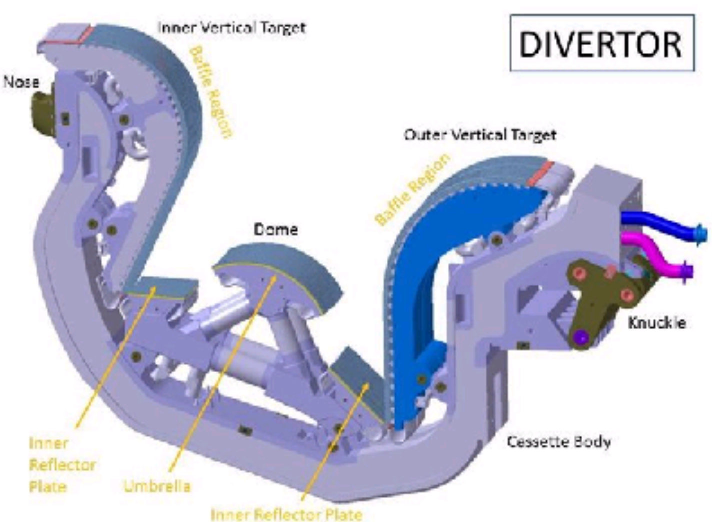
Vp : +2 ~ +7 V

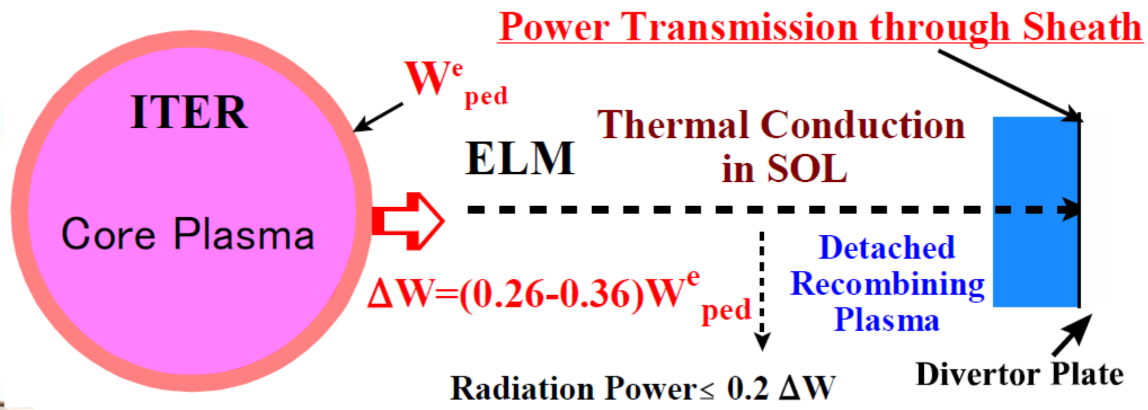




Power onto Plasma-Facing Surface







Steady Power Flux: 10 ~ 20 MW/m^2

Transient Energy Density: 0.2 ~ 2.0 MJ/m^2

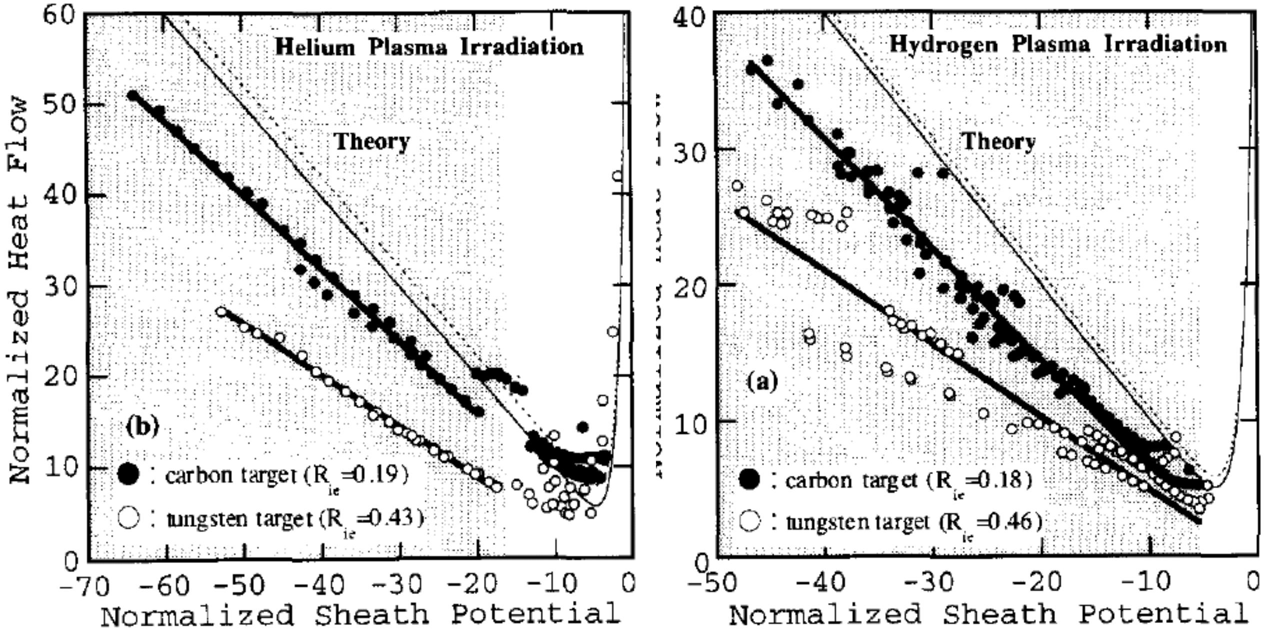
Power Transmission Factor is a key measure to determine the power flux to the plasma-facing surface !

Edge Plasma Physics — Sheath Physics — Material Engineering

Present Status for Power Transmission Factor (PTF)

S. Masuzaki et al.: J. N. M. **223** (1995) 286

Maxwellian Plasmas
Normal Tungsten W



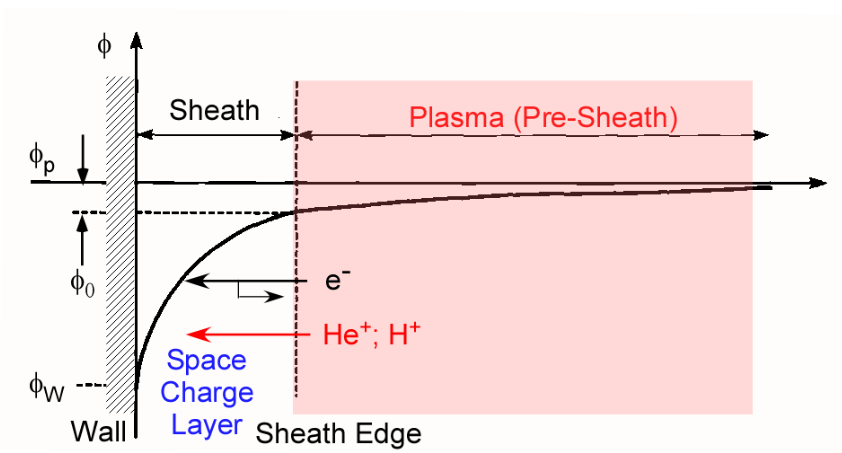
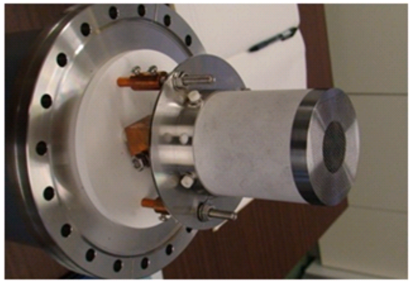


Fig. 6. The normalized plasma heat flows from experiment and theory. Thin solid curves are obtained from Eq. (3), simple sheath theory, that does not include the effects of ion reflection and surface recombination. Dashed lines come from Eq. (5) with $R_{ie} = 0$ and typical electron temperatures $T_e = 15$ eV for hydrogen plasma and 10 eV for helium plasma are substituted, respectively. The hatched regions are the ion saturation region, in which ion contribution to the heat flow dominate. The experimental data points are fitted by the bold solid lines. (a) Hydrogen plasma → carbon or tungsten, (b) helium plasma → carbon or tungsten.

Calibration for the Relation between T_W and P_{input}

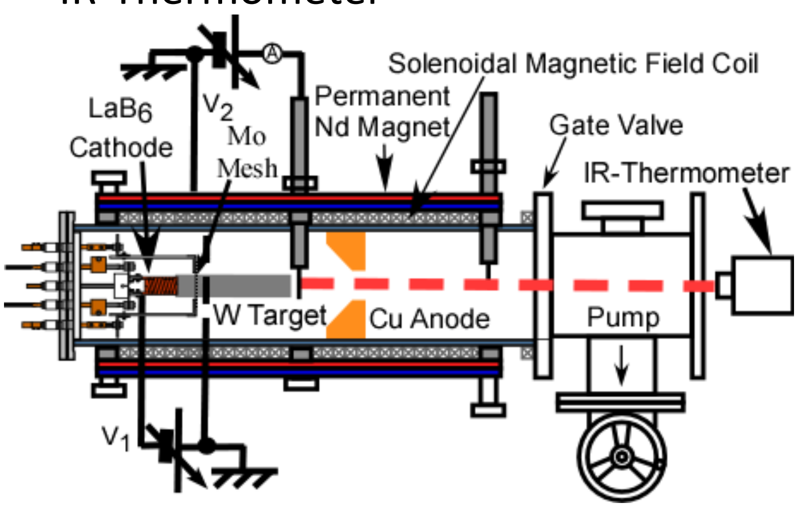


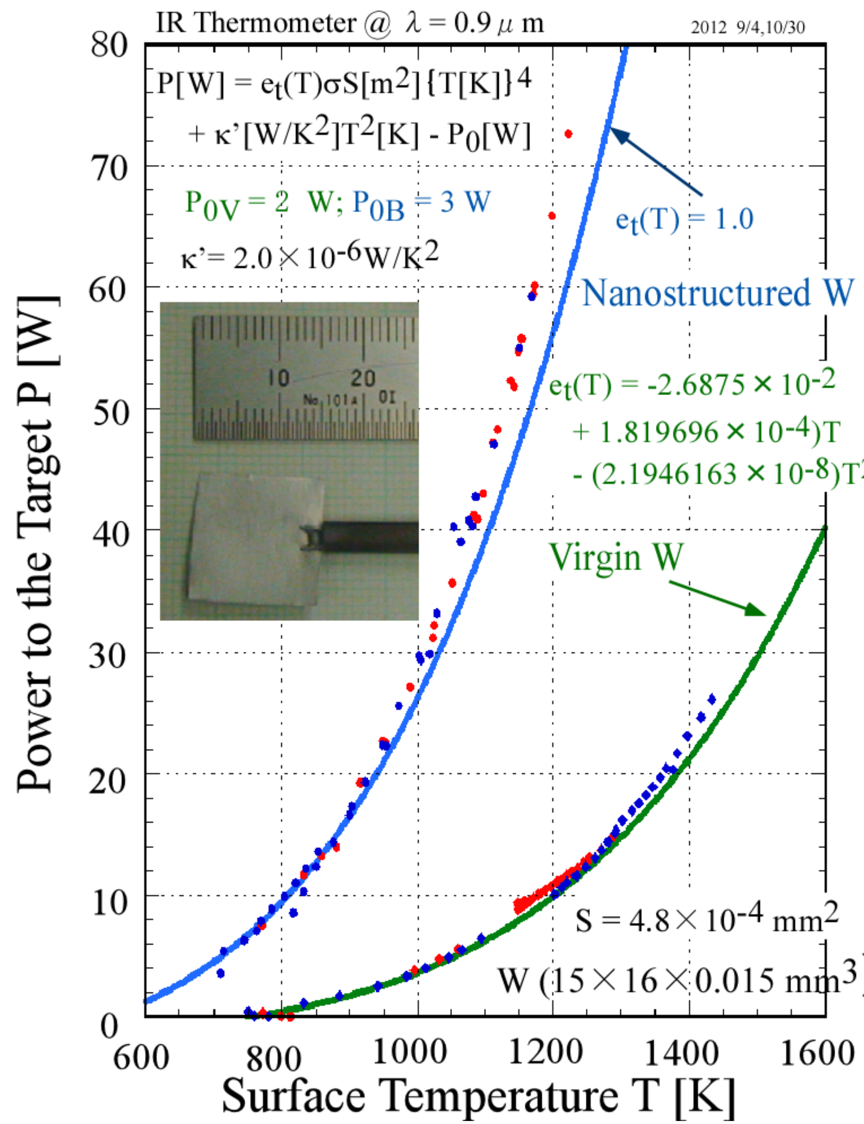
Electron Beam Source

IR-Thermometer

Tungsten Temp.

Input Power





Modified PTF Analysis (He^+ - W)

$$eQ_i / j^+ = e|\varphi_P - \varphi_W|(1 - R_{iE}) + e\varphi_i - e\varphi_W \gamma_{Aug}$$

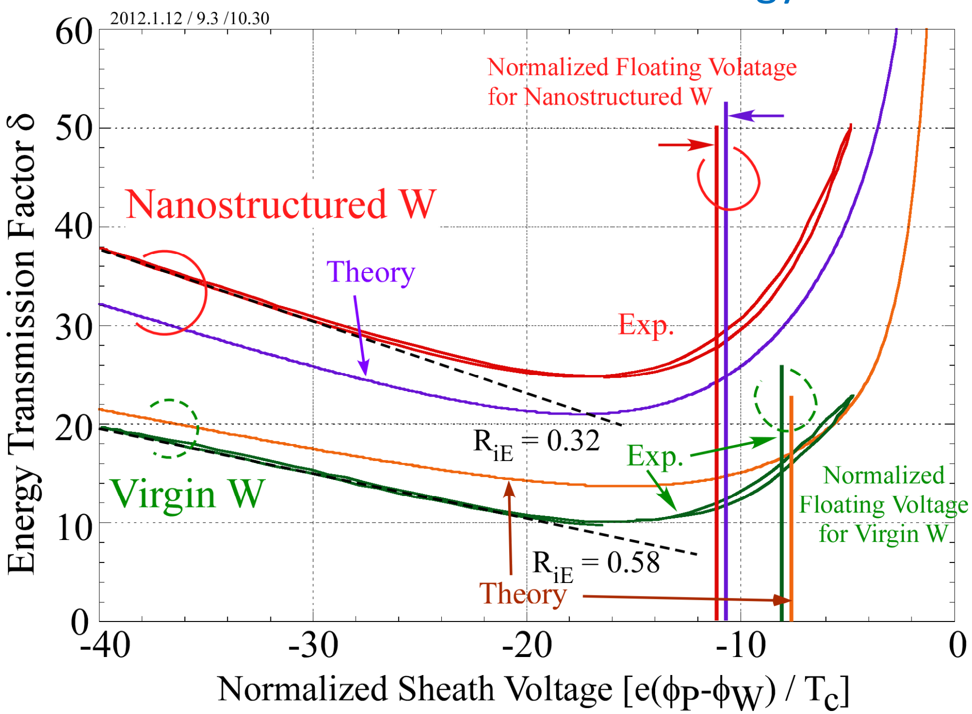
Impact Energy

Effective Surface Recombination Energy

$$eQ_e / j^+ = 2T_c(1-\alpha)\chi_c \exp\left(-\frac{e(\varphi_P - \varphi_W)}{T_c} + \frac{T_{eff}}{2T_c}\right) + (2T_h - e\varphi_W \gamma_e)\alpha\chi_h \exp\left(-\frac{e(\varphi_P - \varphi_W)}{T_c\beta} + \frac{T_{eff}}{2T_c\beta}\right)$$

Bulk Electron Energy

Effective Hot Electron Energy



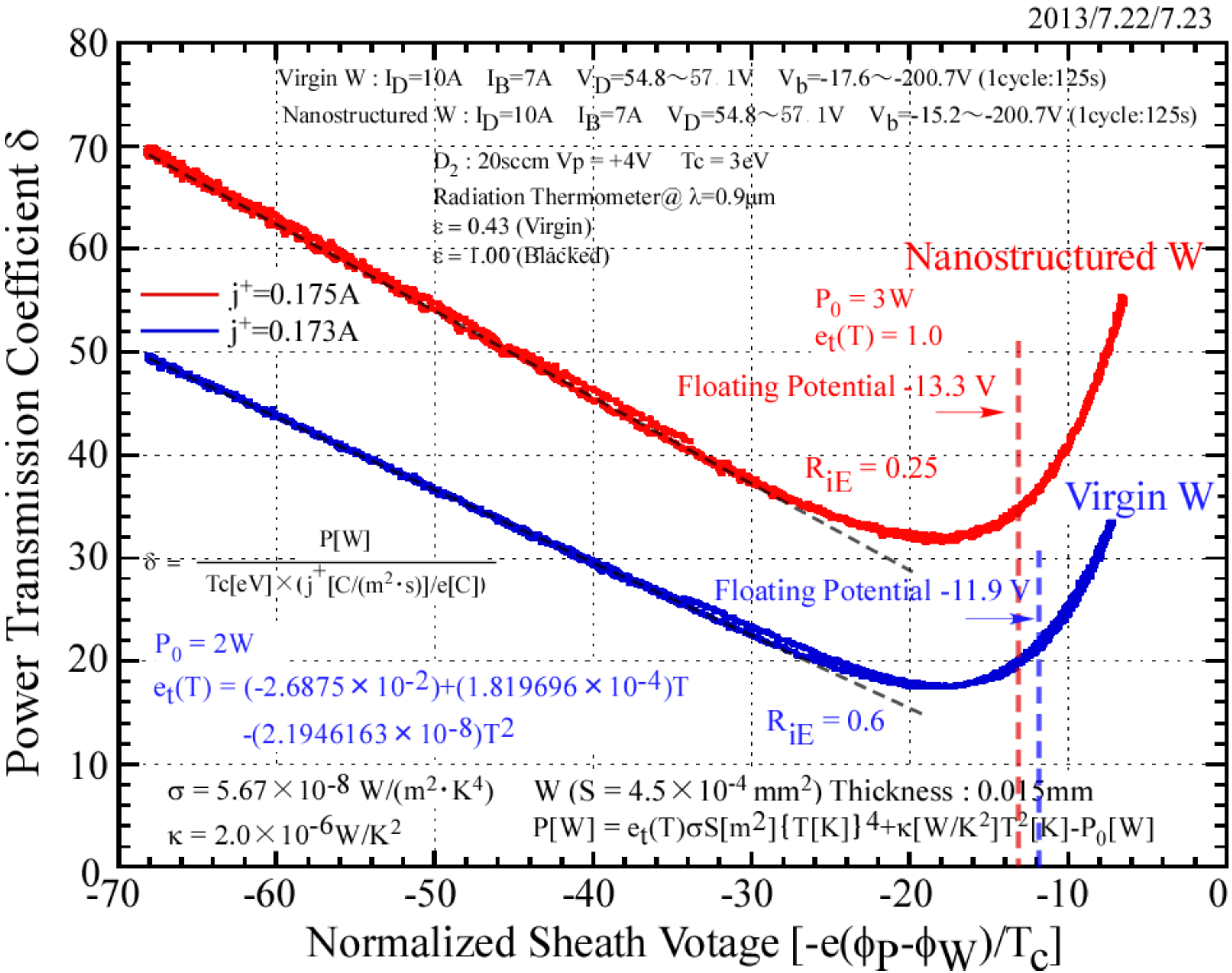
Where γ_{Aug} : Auger electron emission coef.,
γ_e : SEE coef.
$e\phi_w$: Work function of W.

$$\gamma_e(T_h = 30\text{eV}) \approx 0.48$$

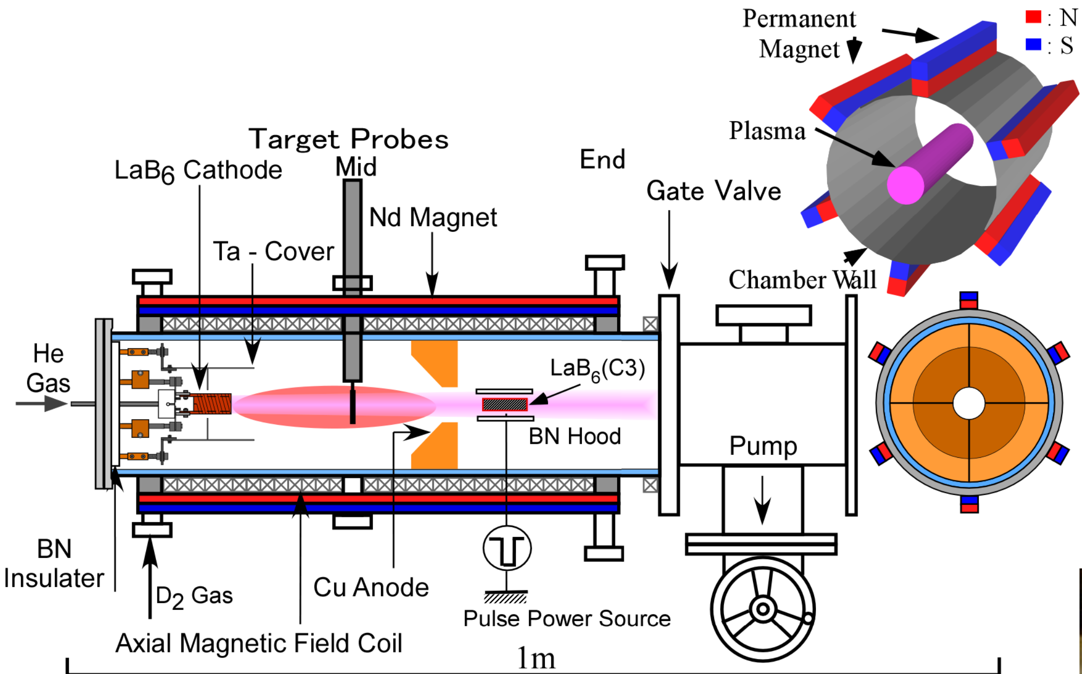
$$\gamma_{Aug} = 0.28$$

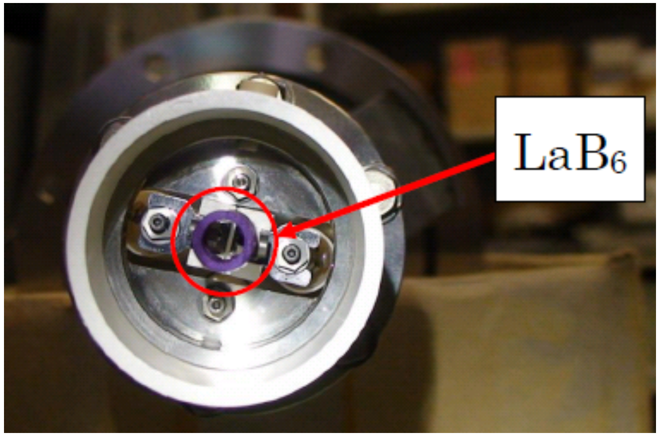
Still we have some gap between experimentally obtained PTF and theoretical analysis !

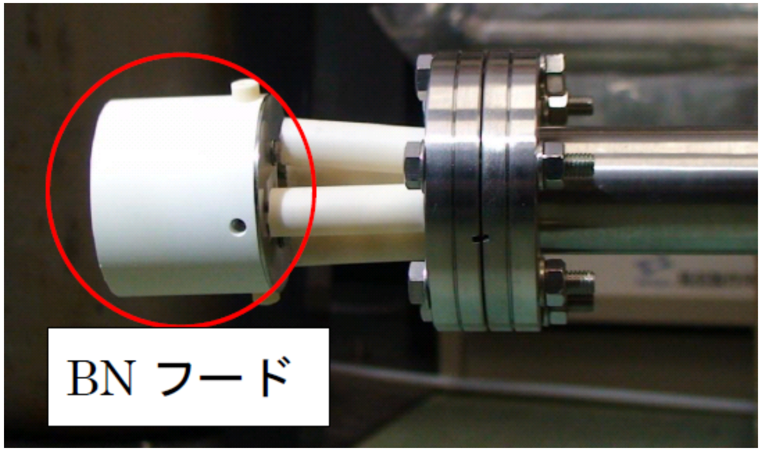
Dプラズマ—W系熱伝達係数

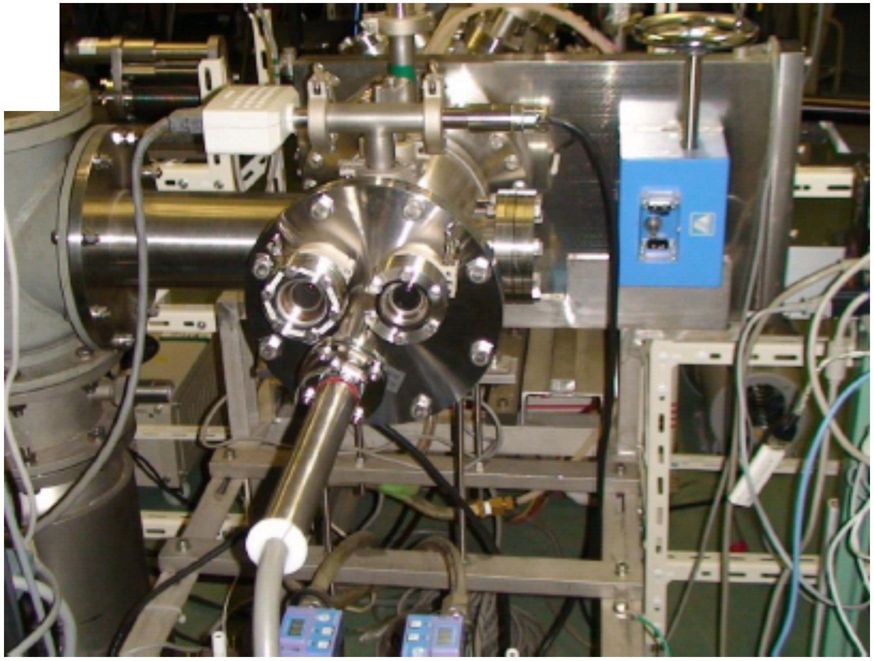


Dプラズマ中Wへの熱パルス

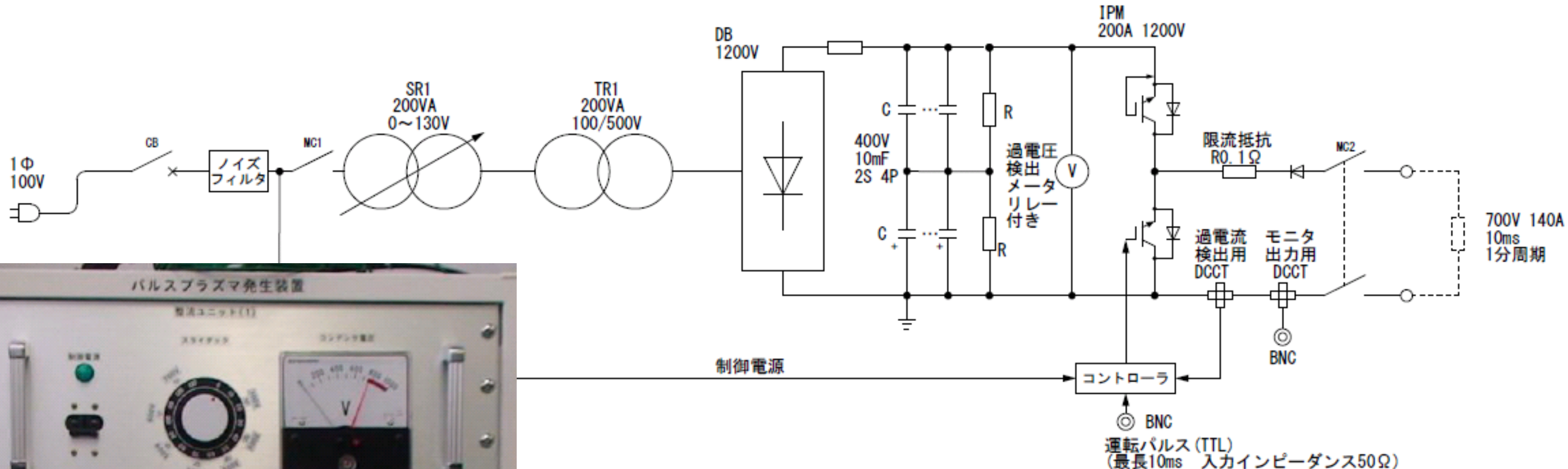








パルス電源



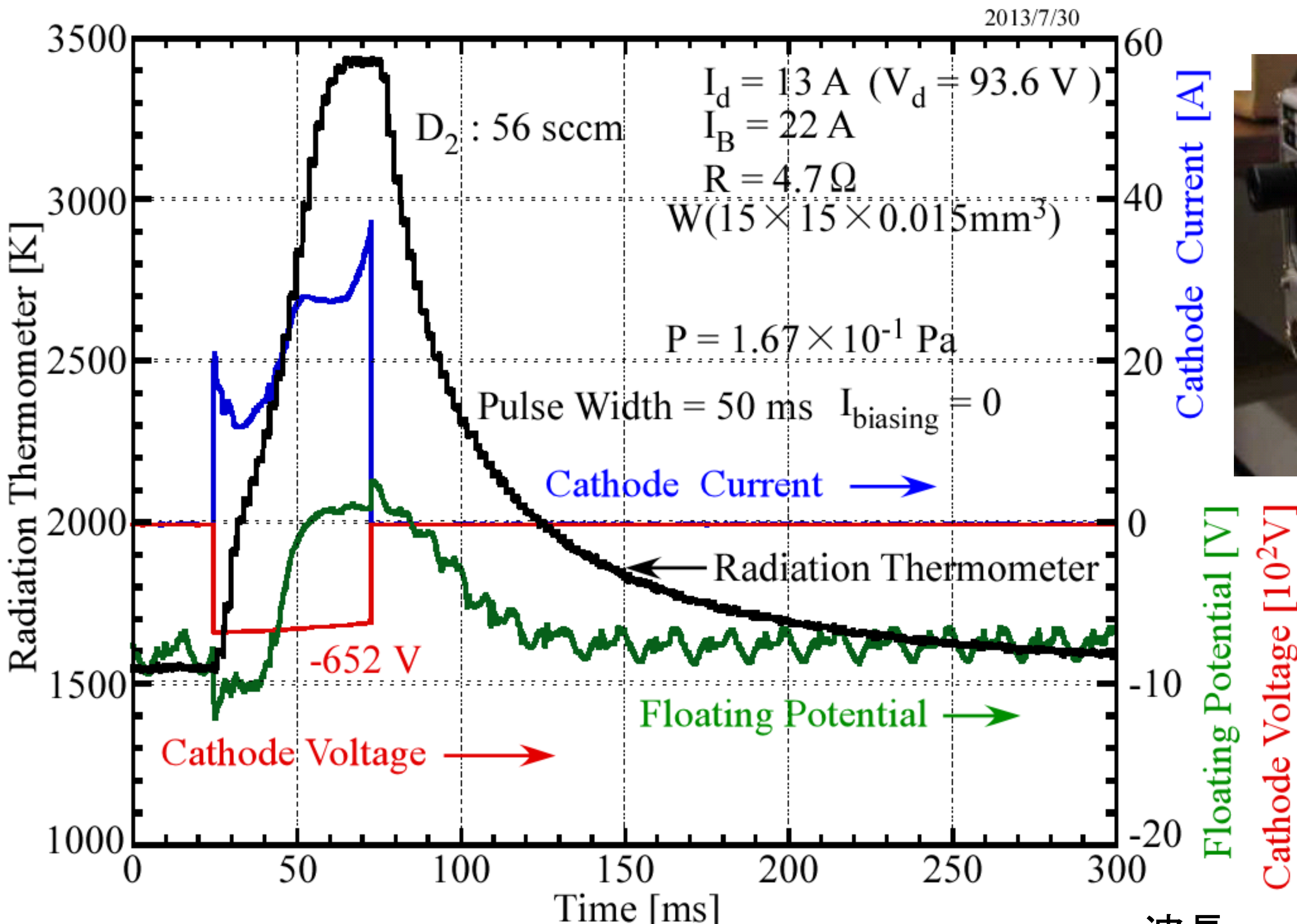
パルスプラズマ発生装置　単線接続図

仕様

出力電圧:750 V;　　出力電流:140 A
出力パワー: 105 kW

パルス長:≤ 50ms;　周期: 1分

Dプラズマ熱パルスに対するWの応答



分光放射率
ε = 0.42（固定）

E ~ 0.1 MJ/m²

Input Power ~ 15 kW

放射温度計（チノー IR-CAS3CS）

波長： 0.9 μm

温度範囲： 600 ~ **3000 ℃**

応答時間： 3 ms (95 %)

Wの分光放射率 e(λ, T)

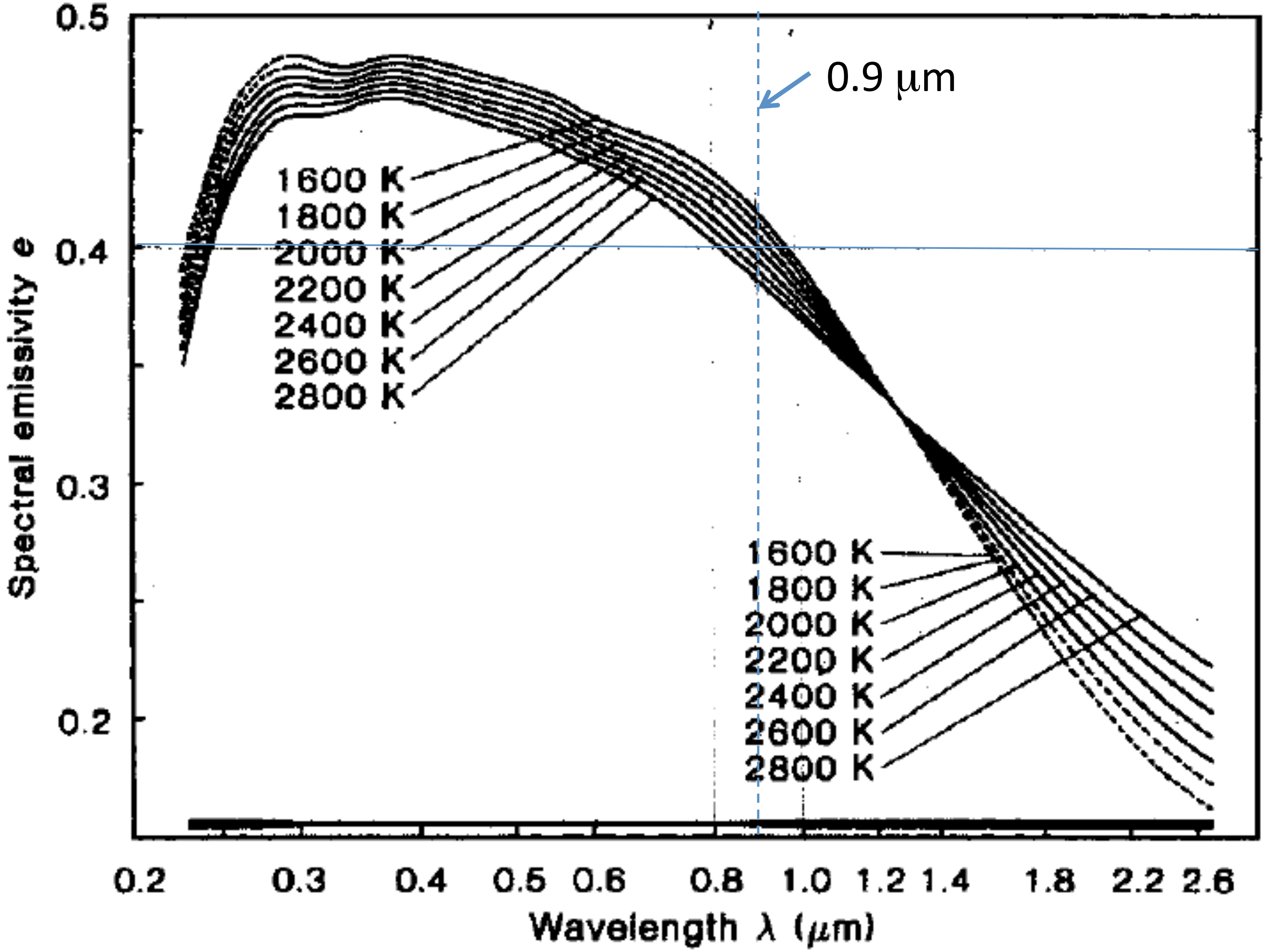
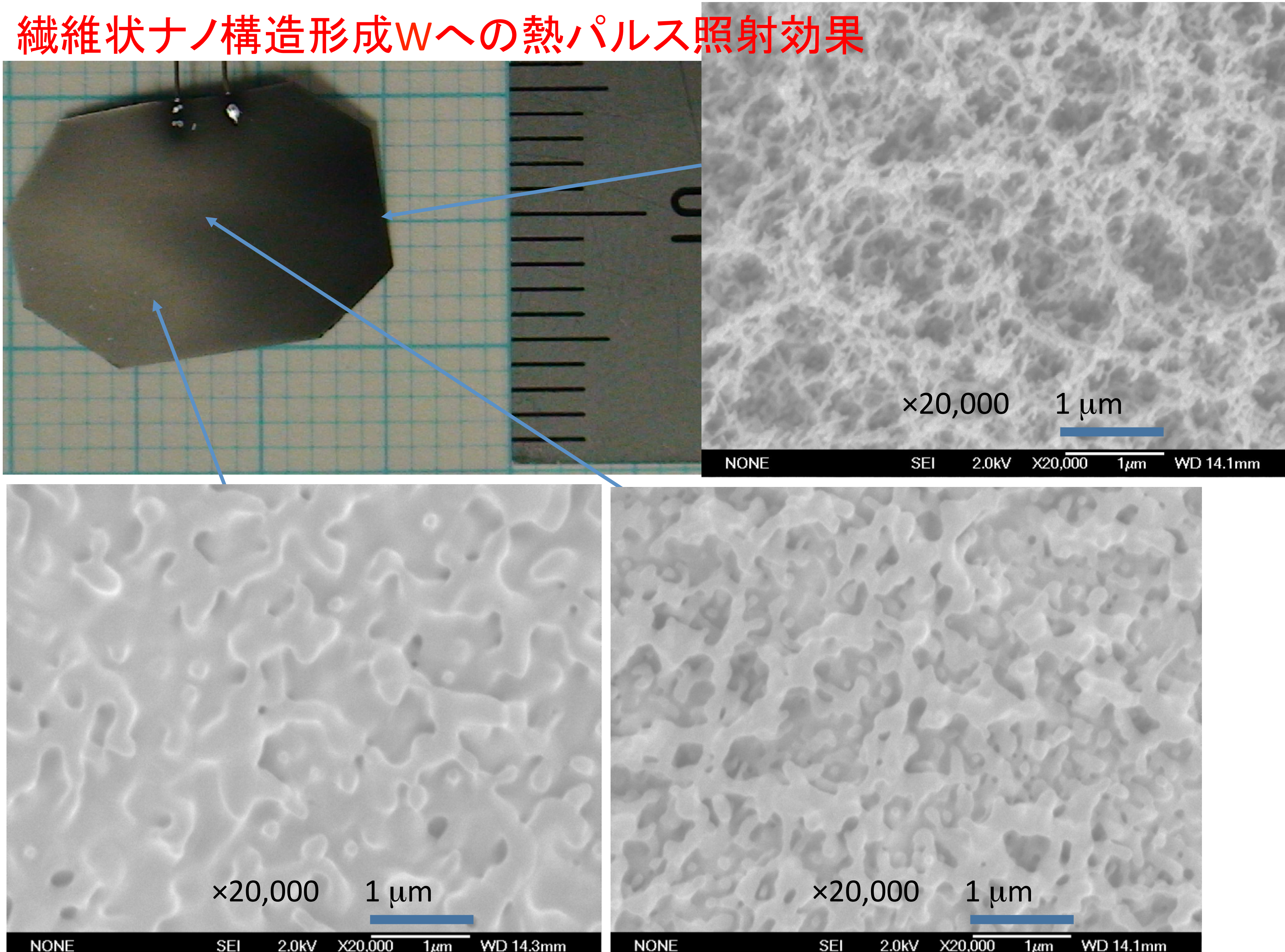
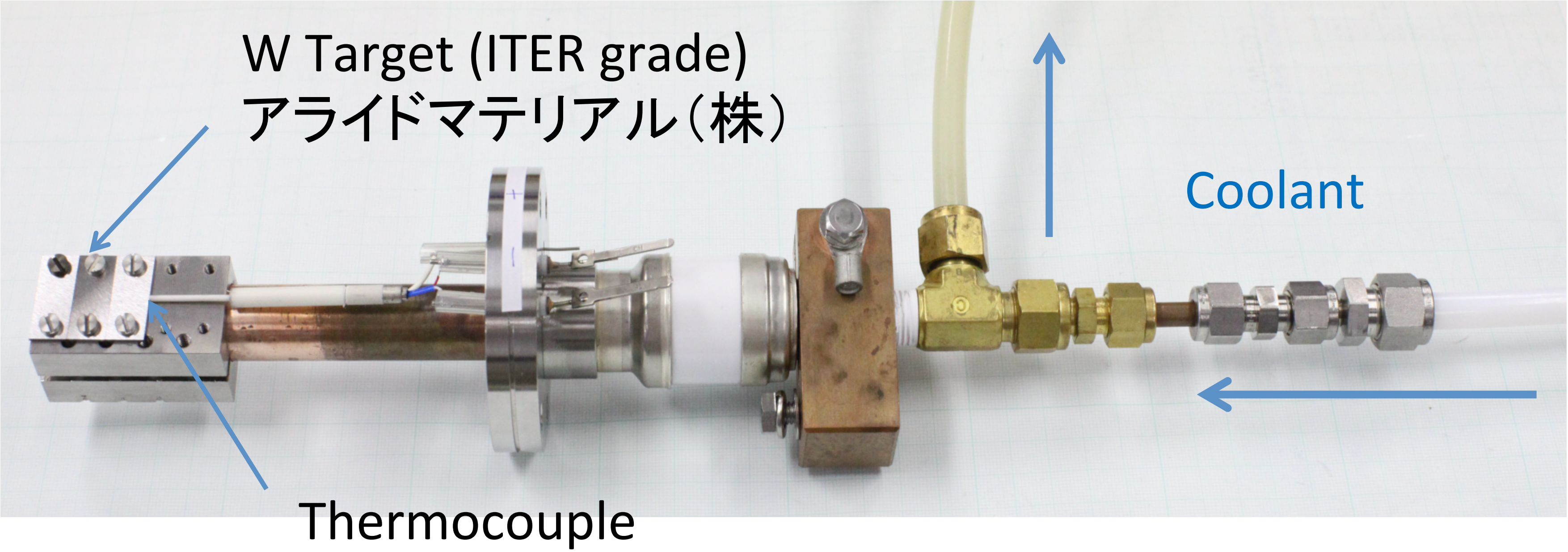


FIGURE 1.20. Spectral emissivity of tungsten according to de Vos [1.37].

繊維状ナノ構造形成Wへの熱パルス照射効果



WへのDプラズマ重照射 準備



まとめ

（1） 高熱流重水素プラズマの生成

（2） 重水素プラズマータングステン系における熱伝達係数の実験的評価 （Virginと 黒色化 Wでの相違）

（3） 重水素プラズマ中におけるタングステンへの熱パルスの効果: 3000 Kを超える昇温。浮遊電位の低下の観測

（4） タングステンへの重水素プラズマの重照射のための直接冷却ターゲットホルダーの製作

今後の予定:

（1） 熱伝達係数の理論的評価

（2） 熱パルスによる溶融過程の調査

（3） 製造方法の異なるタングステンへの重水素プラズマの重照射効果