Report of the First Mirror SWG

Compiled by A. Litnovsky and V. Voitsenya

Research at the Forschungszentrum Jülich (EU)

Compiled by A. Litnovsky

With contributions from: V. Kotov, A. Kirschner, D. Borodin,

D. Reiter, W. Biel, S. Sadakov, M. von Hellermann (FOM)

and TEXTOR Team

Current research activities

Concentration: candidate mirror solutions for ITER diagnostics

Series of comparative tests

(performed jointly with collaborators)

SC Mo mirrors vs. mirrors with nano-film coating

Main results:

- ► Good sputter resistance and adhesion;
- ► Optical characteristics are yet to be assessed;
- ► To be continued.

SC Mo mirrors vs. Rh-coated mirrors [1, 2]

Main results:

- ► Good reflectivity of coatings;
- ► Sputter resistance is yet to be achieved.

Details: presentation of L. Marot today.

1. G. Maddaluno et al., to be presented at the EPS 2007;
2. L. Marot et al., to be presented at ISFNT 8;

Coordination of the FM research within European institutions

Within EFDA contract: TW6-TPDS-DIADEV

FOM (Rijnhuizen, the Netherlands:)

- ► Mo mirrors under detached plasmas: PILOT-PSI;
- ► Temperature dependence of deposition;

Univ. of Basel (Switzerland)

- ► R&D on Rh-coating, including exposures in TEXTOR (FZJ);
- ► Optical and surface characterization of mirrors.

Work on ITER diagnostics within the EU clusters

Within EFDA contract: TW6-TPDS-DIADES

ITER core CXRS

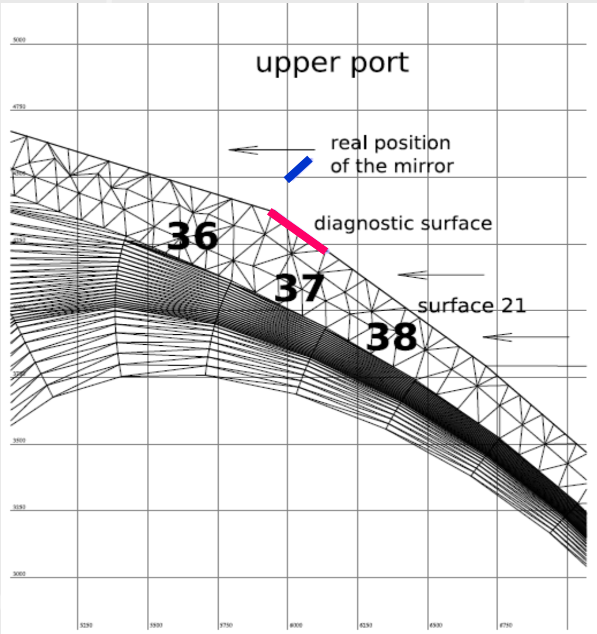
ITER core LIDAR

- Mirror materials and lifetime issues;
- Modeling of mirror performance;
- Mirror and shutter design;
- Participation in the design of diagnostic tube (for CXRS).

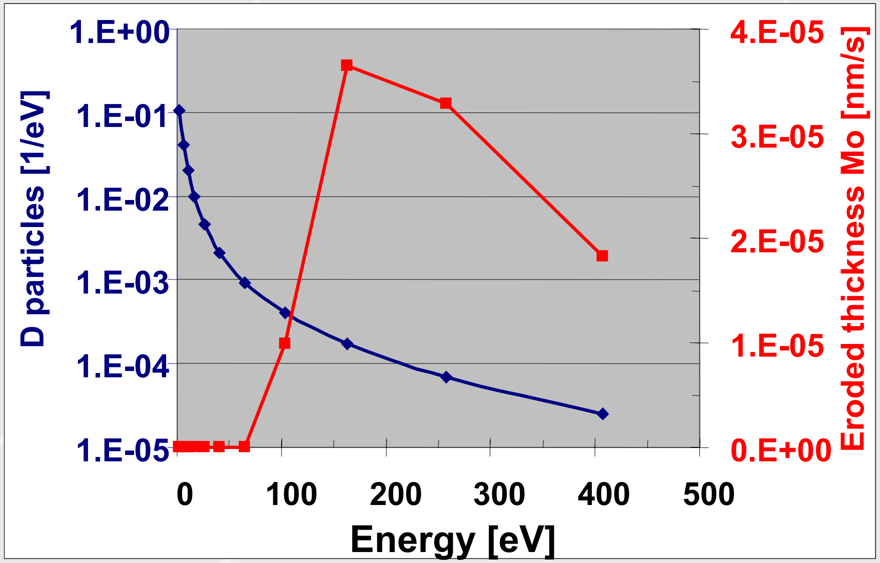
Modeling of mirror performance

B2-EIRENE package was used to model the plasma/neutral environment near the first mirror of the CXRS system

First results



(a) Layout of the diagnostic surface



Normalized energy probability distribution of D atoms on the diagnostic surface and resulting Mo erosion rate

Estimated maximum erosion of up to 1 µm during the ITER lifetime should not be a problem for SC Mo first mirror

Plans 2007

Experimental activity

- **Further mirror tests in TEXTOR and PILOT-PSI;**
  - **Material choice (Rh- and nano-film coated Mo mirrors)**
  - **Deposition mitigation (temperature and gas pressure effect)**
- **Experiment in the AUG (jointly with IPP Garching):**
  - **Mirrors in the divertor and pump-duct**
  - **Temperature effect on the deposition**
- **Experiment in the DIII-D (jointly with DIII-D Team):**
  - **Mo and Rh-coated mirrors in the midplane location**
  - **(details are provided below)**

Modeling

- **CXRS and LIDAR diagnostics to be addressed;**
- **Be as a first wall material;**
- **Deposition on the first mirror;**
- **Non-convective and convective transport;**
- **Better edge plasma parameters.**

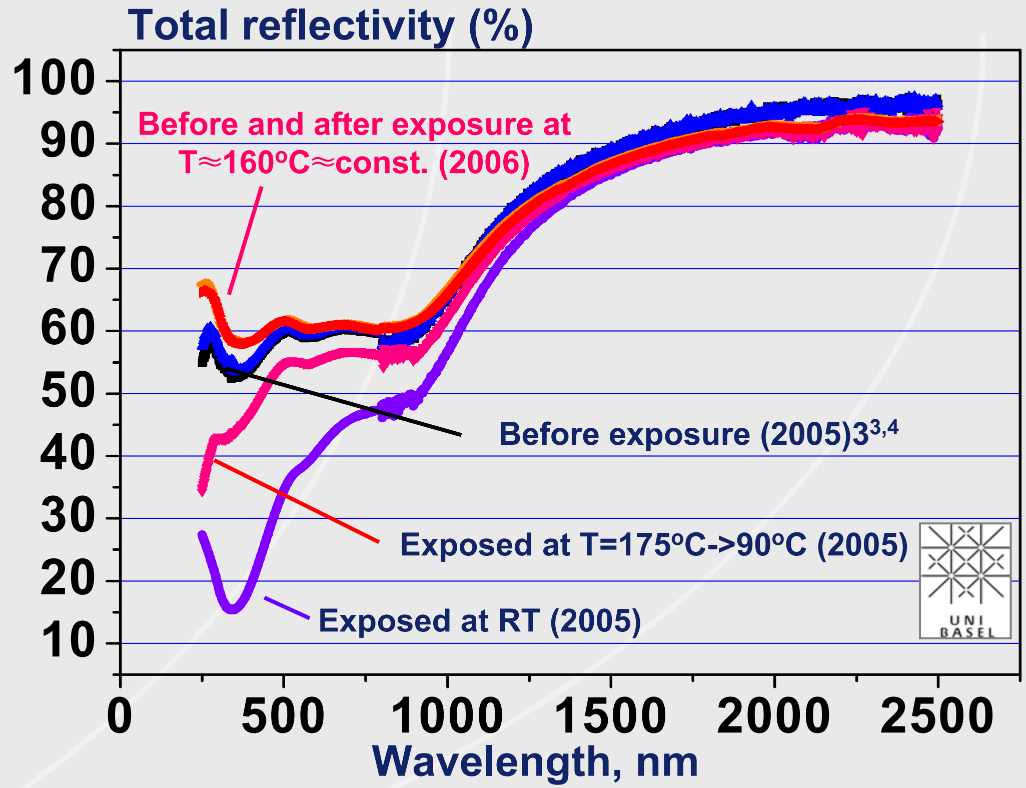
First mirror activities at the DIII-D

Compiled by D. Rudakov

Carbon deposition mitigation

Experiments in the DIII-D divertor

Heating of mirrors may increase the chemical re-erosion of deposited layers on the mirrors thus cleaning them and restoring their reflectivity



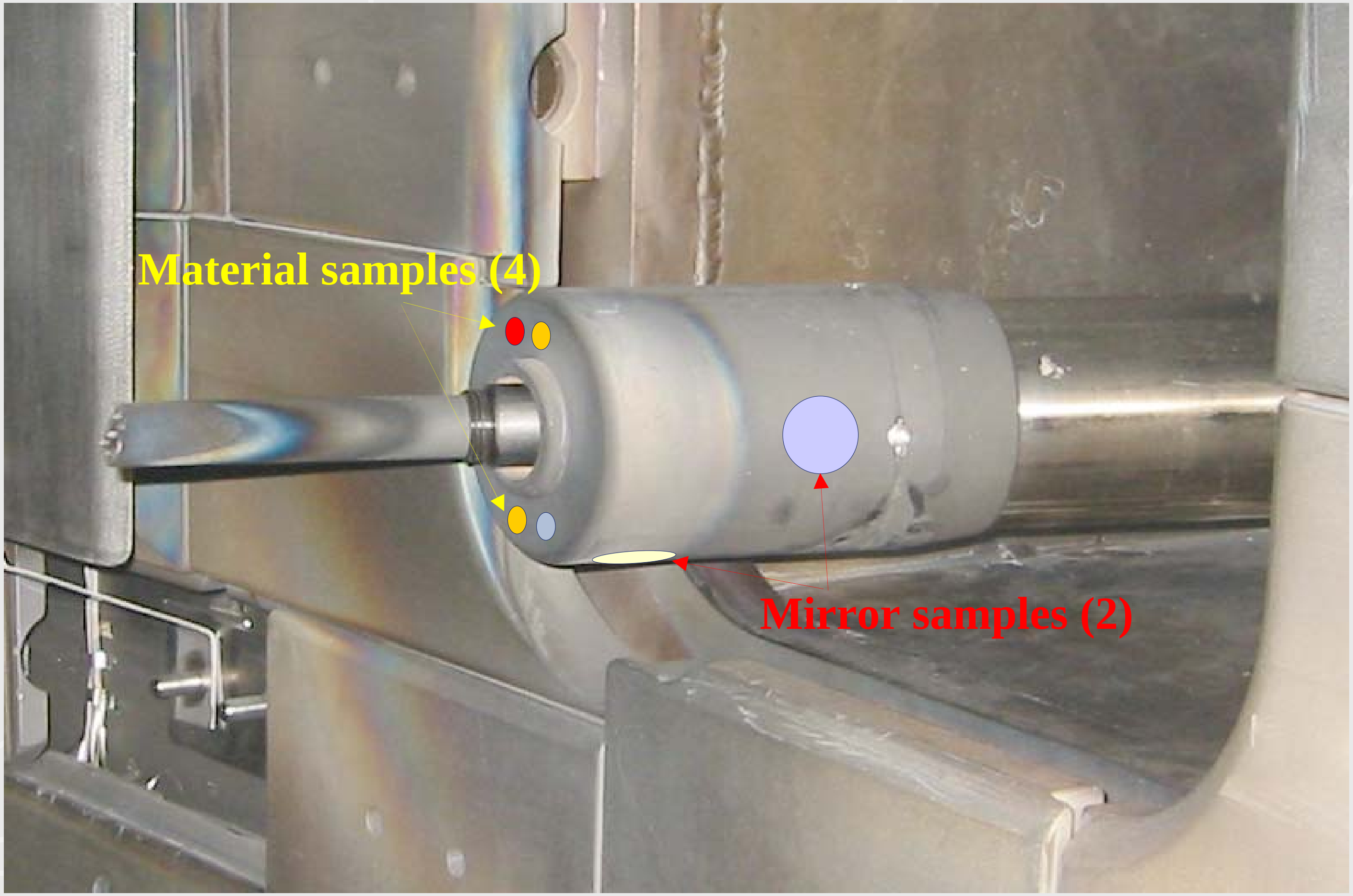
Data:

[3]D. Rudakov et al, Rev. Sci. Instr. 77, 10F126 (2006);
[4]A. Litnovsky et al., subm. to Fus. Eng. and Design;
[5] J.W. Davis et al, JNM 155-157(1988), 234;
[6] E. Vietzke et al. Fus. Technol. 15 (1989), 108.

MiMES (Midplane Material Evaluation Sample)

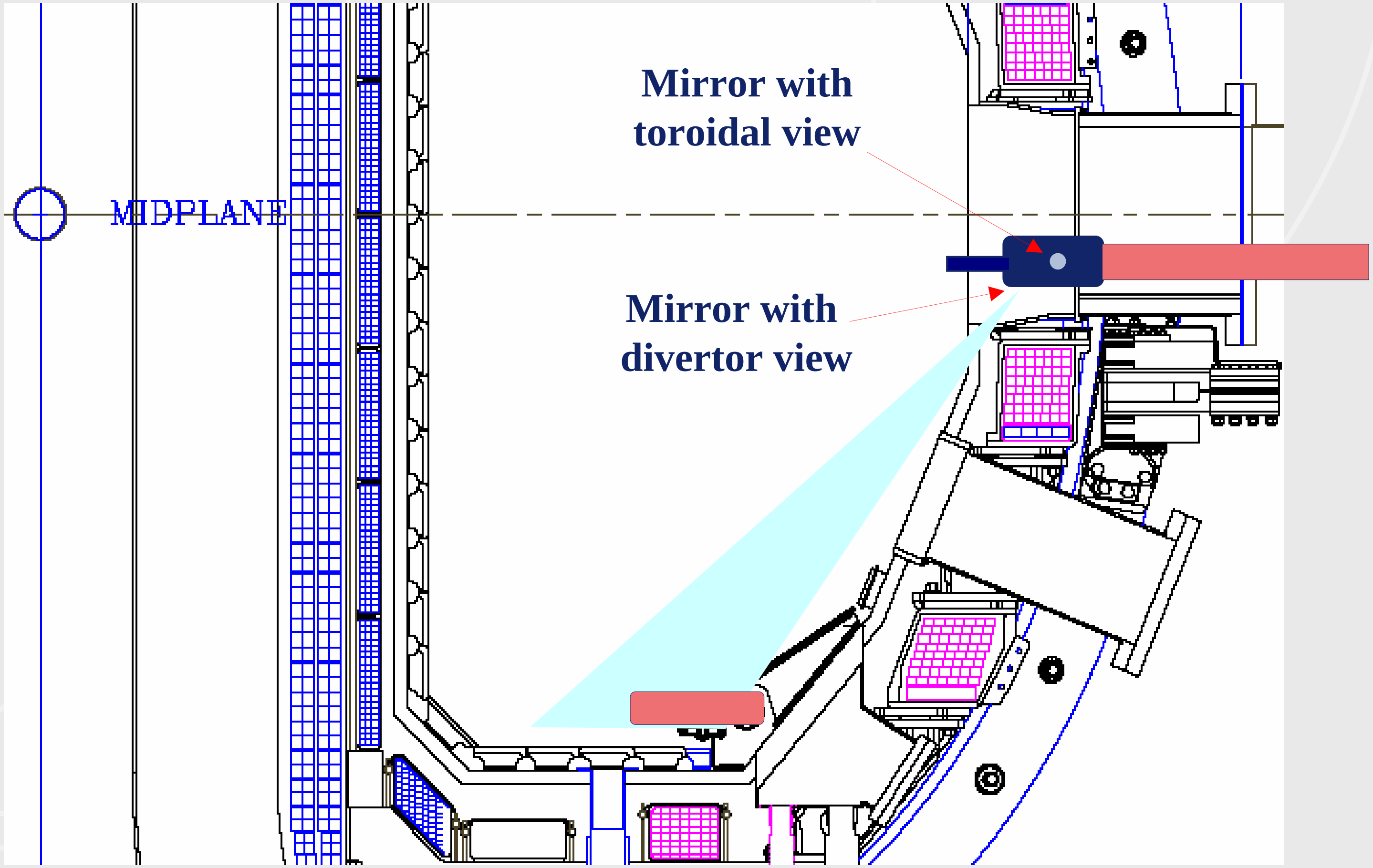
Research objectives:

- ► Net erosion/deposition measurements (integrated over exposure time)
- ► Tritium retention in the first wall elements (including tile gaps)
- ► **Diagnostic mirror tests**



Samples installed on the outer shield of the reciprocating mid-plane probe

- MiMES should be ready for installation on DIII-D in June 2007
- Two mirrors with different views can be exposed simultaneously
- Piggyback exposures of Mo and Rh-coated mirrors are planned in July



Argonne NATIONAL LABORATORY

... for a brighter future

ITER MSE Diagnostic First Mirror Analysis

Jeffrey N. Brooks, Jean Paul Allain, Ahmed Hassanein

Argonne National Laboratory

12th ITPA Topical Group Meeting on Diagnostics

Princeton Plasma Physics Laboratory, March 26-30 2007

U.S. Department of Energy

UChicago Argonne LLC

Office of Science U.S. DEPARTMENT OF ENERGY

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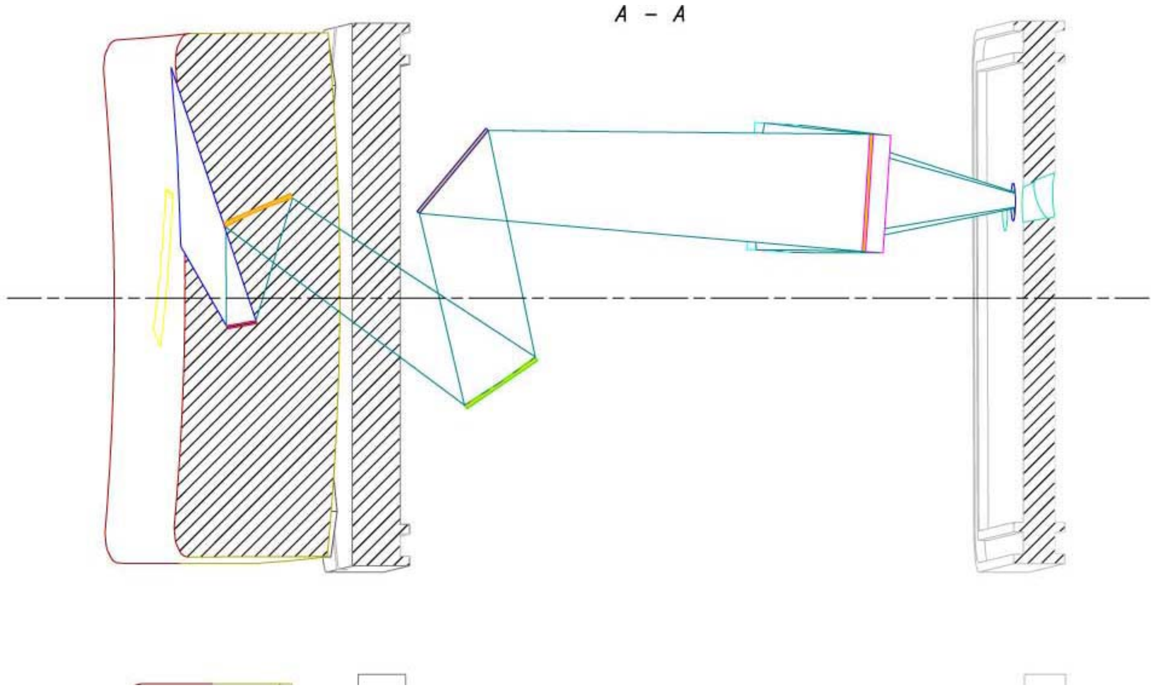
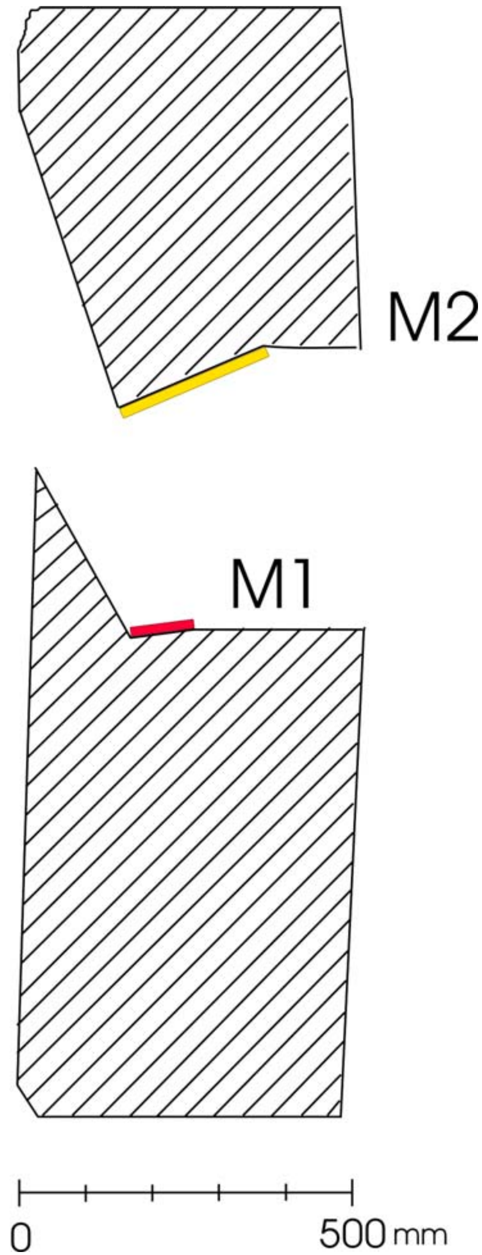
Motional Stark Effect (MSE) First Mirror Analysis at Argonne

- **Goals:**
- Compute particle fluxes to MSE/midplane diagnostic first mirror for ITER D-T high power shots, burn phase.
- Assess effect of particle fluxes on mirror performance (reflection, phase change, etc.), via computer modeling.
- Initiate analysis of plasma transient (ELM's, disruptions, etc) effects on first mirror.
- Identify critical issues for future modeling and experimental work**.**
- **Method:**
- Use Code Package-OMEGA analysis for ITER to define particle fluxes, energies, to first wall/diagnostic-aperture. (D, T , He charge-exchange, D^+,T^+, He^{+2}, Be^{+k}, W^{+j} ion fluxes)
- Use coupled MC-Mirror/TRIM-SP codes, and above boundary fluxes to compute fluxes to first mirror.
- Use IMD code to assess effects on optical properties of mirror.
- Use Code-Package HEIGHTS analysis for ITER to define plasma transient (ELM's etc.) heat/particles to mirror location
- [7] J.N. Brooks et al., Physics Plasmas13(2006), [8] T.D. Rognlien et al., PSI-17. J. Nucl. Mater, tbp

MSE Geometry





- First mirrors (M1 and M2) located inside blanket shield module (BSM)
- Geometry obtained from ITER-CATIA CAD models (A. Malaquias, C. Walker)

Key Results

- Only ~6 % of CX D-T hit the first mirror. The module design appears to be a good one.
- For D-T ions entering the aperture, the fraction hitting the mirror (as atoms) is about 1%.
- He fluence to the first mirror (via initial crude-model only) is at the threshold for bubble formation in a Mo mirror.
- Molybdenum mirrors lose ~1-μm, over a 5-yr ITER operation schedule.
- Be deposits of about 2500 nm on the mirror in a 1-yr ITER (at 1000 shots/yr and 400 sec/ITER shot)
- For polarized light, Be deposition on the Mo mirror shifts the high-reflectance region towards more near-normal incidence of light. The overall optical response reaches a steady-state for > 40-nm deposition of Be.
- Tungsten deposition is negligible. Iron deposition may be significant.
- For *non-transient* plasma operation: no significant transport of material from the ITER carbon divertor to the MSE mirror. However, *ELM's and other transients* may cause significant transfer.

Investigations in PISCES-B (USA)

G. De Temmerman, M. Baldwin, R. Doerner

Center for Energy Research, University of California at San Diego, USA

Impact of beryllium deposition on the reflectivity of the first mirrors

Motivation

► Experiments in PISCES-B simulate Be erosion from ITER first wall, subsequent transport in the divertor (SOL plasma flow), and interaction of the divertor targets with Be-containing plasma

➡ Presence of Be in the divertor plasma may mitigate erosion of the graphite targets (and subsequent carbon migration) [7]

➡ Formation of Be-rich layers in direct line-of-sight locations from the plasma (no long-range migration for Be) [8]

► Until now it was assumed that Be deposition will make the coated mirror behave like a Be mirror beyond a given deposited thickness (see report from J.P. Allain *et al*)

Aim of the experiments:

► Assess the effect of Be deposition on Mo and Cu mirror reflectivity

► Collect data on the “optical quality” of redeposited Be layers (input for future modelling)

[7]M.J. Baldwin, R.P. Doerner, Nucl. Fusion, 46 (2006), 444;

[8]M. Baldwin *et al,* J. Nucl. Mater.,337-339 (2005) 590

Main findings

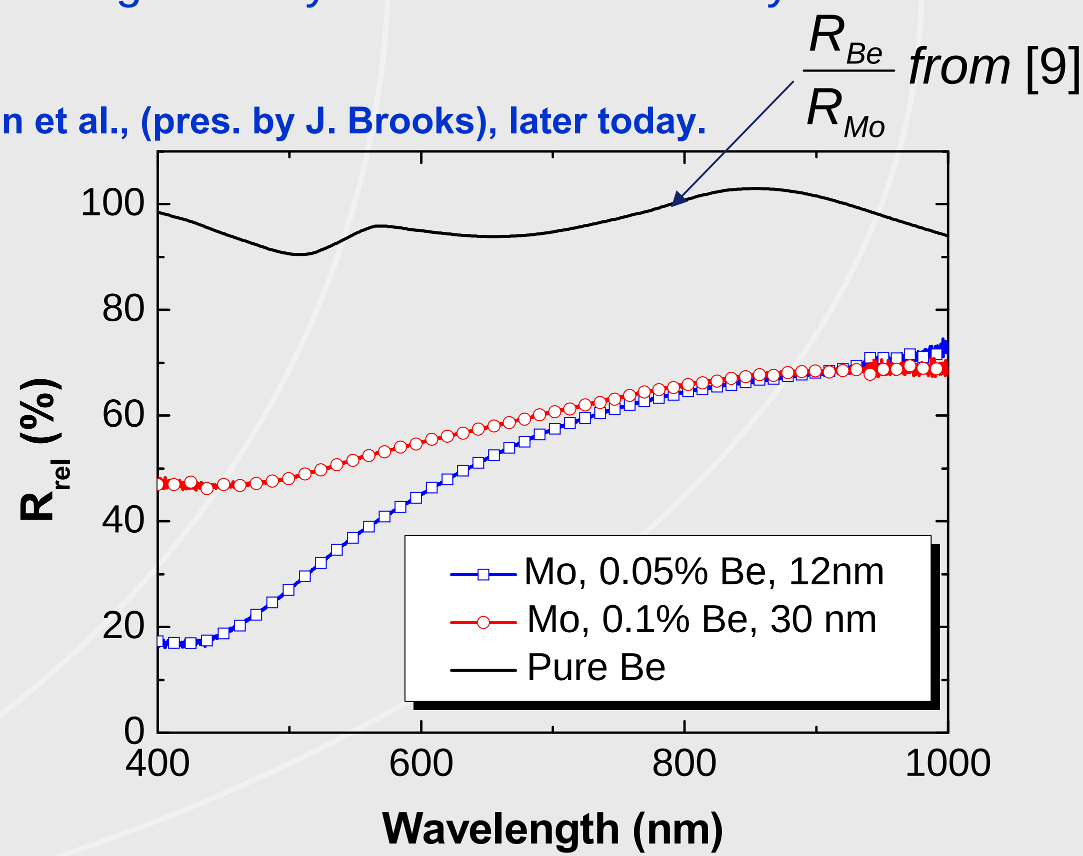
- Mirror reflectivity strongly decreased by thin Be-rich layers
- Reflectivity of coated mirrors significantly lower than reflectivity of bulk Be mirrors

Details: talk from G. De Temmerman et al., (pres. by J. Brooks), later today.

Example of Mo mirrors exposed to similar plasma conditions but with different Be fraction in the plasma

$$R_{rel} = \frac{R_{exposed}}{R_{virgin}}$$

For investigations of Be mirrors, see also [10, 11]



Future work: characterization of deposited layers (roughness, density…) and extrapolation for ITER mirrors

[9] Handbook of optical constants of solids, ed. E.D. Palik, Acad. Press, 1985 and 1991
[10] V. Voitsenya et al., JNM 313-316, 2003, 112
[11] V. Voitsenya et al., JNM 329-333, 2004, 1476

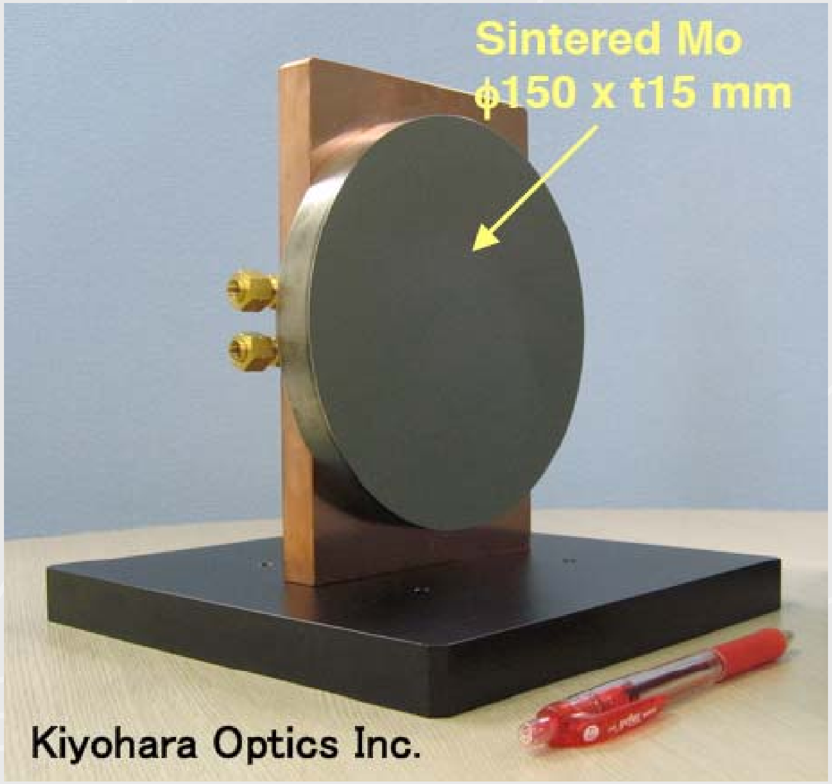
Investigations at the JAEA (Japan)

Compiled by Y. Kawano

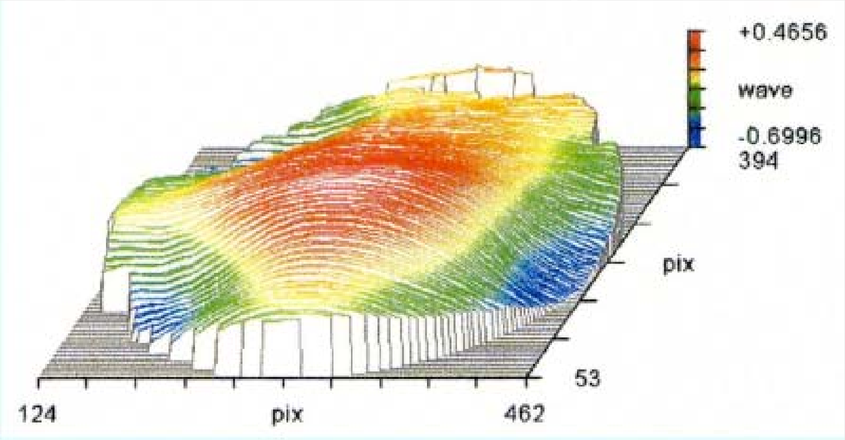
Fabrication test of plasma facing mirrors in JAEA for ITER poloidal polarimeter[12]: sintered Mo

Sintered Mo vs. ⟺ **Single crystal Mo**

Sintered Mo	Single crystal Mo
-- available for required mirror size (ϕ=140~200 mm) as one plate	-- not available for required mirror size as one plate
-- low cost	-- expensive



Flatness PV 1.17λ (λ=632.8 nm)
RMS 0.24λ (λ=632.8 nm)



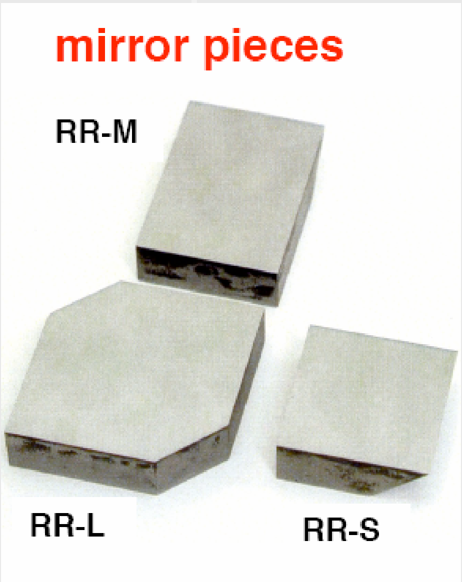
Reflectivity 57% (λ=632.8 nm)

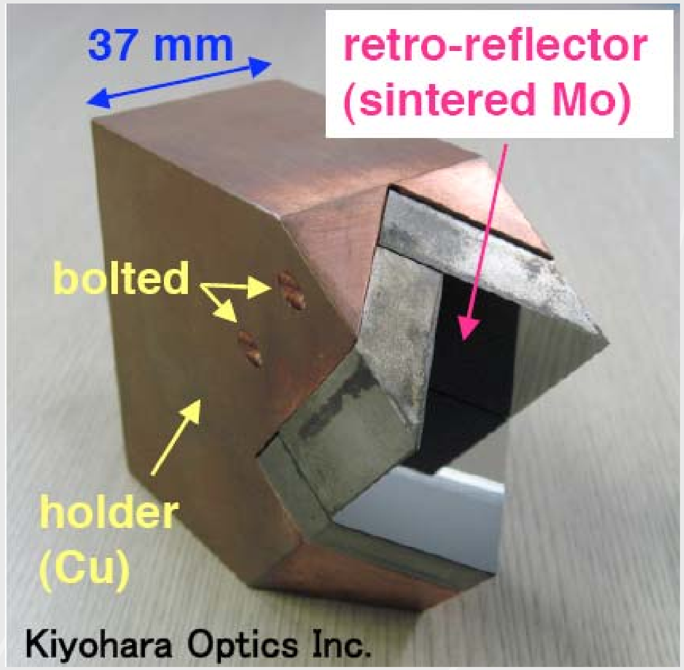
cf. reference values
58% for 0.9-1.1 μm
98% for 10.6 μm

⟹ ***Good result***

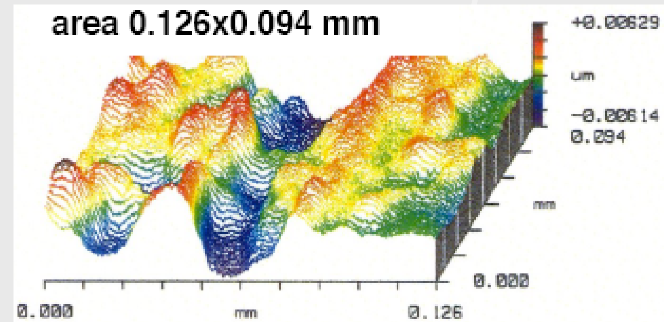
[12] Y.Kawano et al., 23rd JSPF meeting, Tsukuba (2006).

Retro-reflector: sintered Mo





Roughness
PV: 12.4 nm
RMS: 2.43 nm
(@center of RR-L)



Accuracy of beam axis is ~3x10^{-3} rad
--> satisfaction of ~1x10^{-3} rad
(~1 cm at the exit of port plug) is in the scope

Future work: **Design and fabrication test including more detailed mirror mountings**

Technology development for fusion diagnostic applications at TNO (EU)

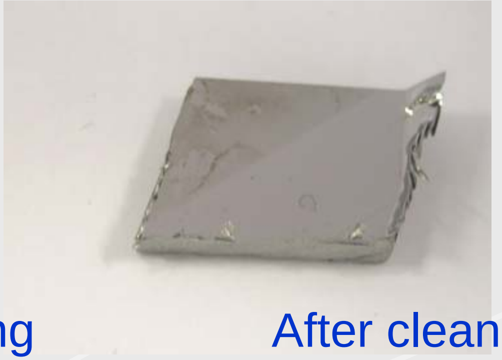
Contr. W. Vliegenthart, G. Gubbels, B. van Venrooy, R. Versluis, A. Storm

Mirror cleaning

5 hrs cleaning under Hydrogen radicals

Next step: determining of cleaning rate on well defined samples
- results expected after July

Before cleaning



After cleaning

TNO Science & Industry

willem.vliegenthart@tno.nl

Manufacturing of mirrors from single crystal Mo and W

Goal: off-axis a-spherical mirrors to get "total" freedom in optical design

Tools: Grinding tool on diamond turning lathe, Corrective polishing.

2006: experiments on grinding wheels, tool settings. (on small diameter)
evaluation: surface error, surface roughness

fig 1: Mo concave mirror

Current status:

on Molybdenum
- surface accuracy: 45nm rms
- surface roughness: 13 nm

on Tungsten
- surface accuracy: 144 nm rms
- surface roughness: 45 nm

(Without additional polishing !)

2007: Continuing experiments on: - tooling,
- erosion tests in TEXTOR

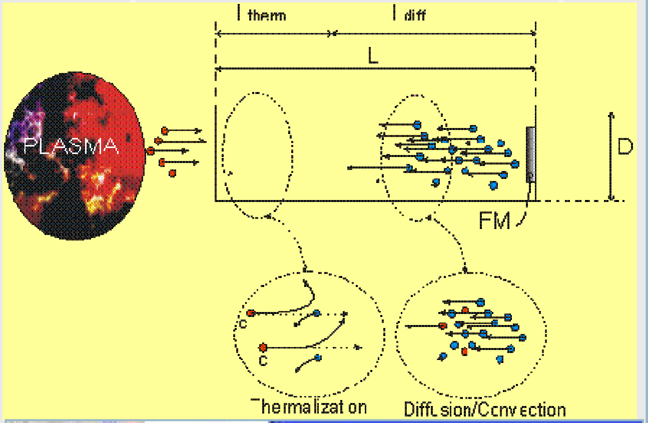
Manufacturing prototype aspherical mirror (10 cm diameter)

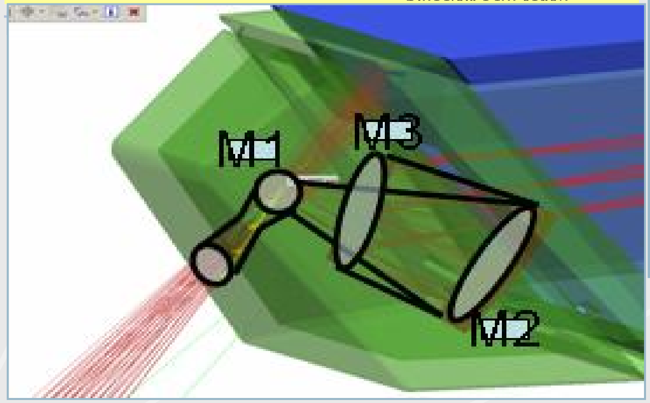
Contamination control

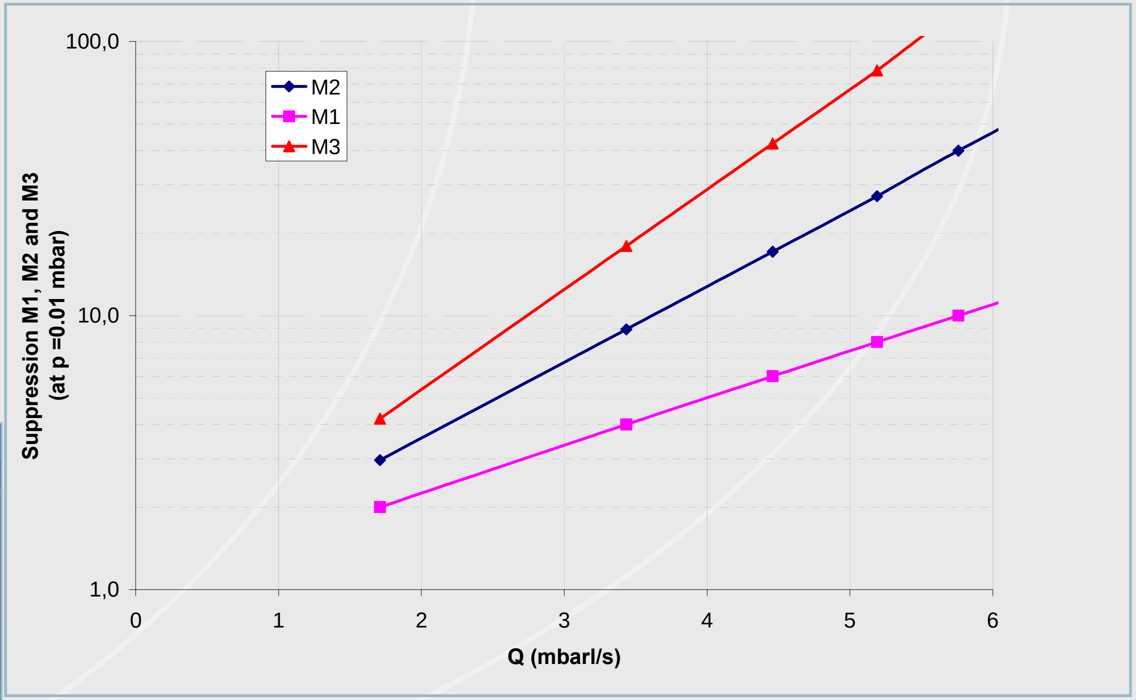
Goal: To protect diagnostic mirrors from by carbon deposition

► Thermalisation of particle influx by hydrogen–carbon collisions

► Convective suppression of carbon diffusion







Carbon neutrals suppression for a port pressure of 0.01 mbar

example: ITER core CXRS

Incoming particle (C) flux: 10e18 /(m s)

Distance m1 to blanket surface: ~ 30 cm

Average diameter: 10 cm

Conclusions:

suppression for C-H2 at 4 mbar l/sec

M1: R=5, **M2:** R=10, **M3:** R=30

Mirror work at CIEMAT (EU)

Compiled by E. Hodgson

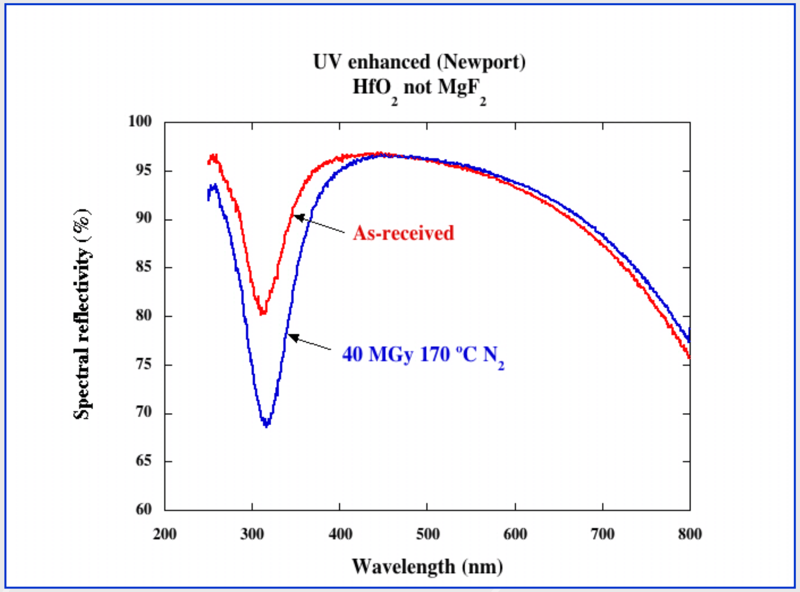
Irradiation tests

Work on high quality secondary coated mirrors

Manufacturers specifications not always reliable:

HfO_2 for MgF_2 ==> activation ?

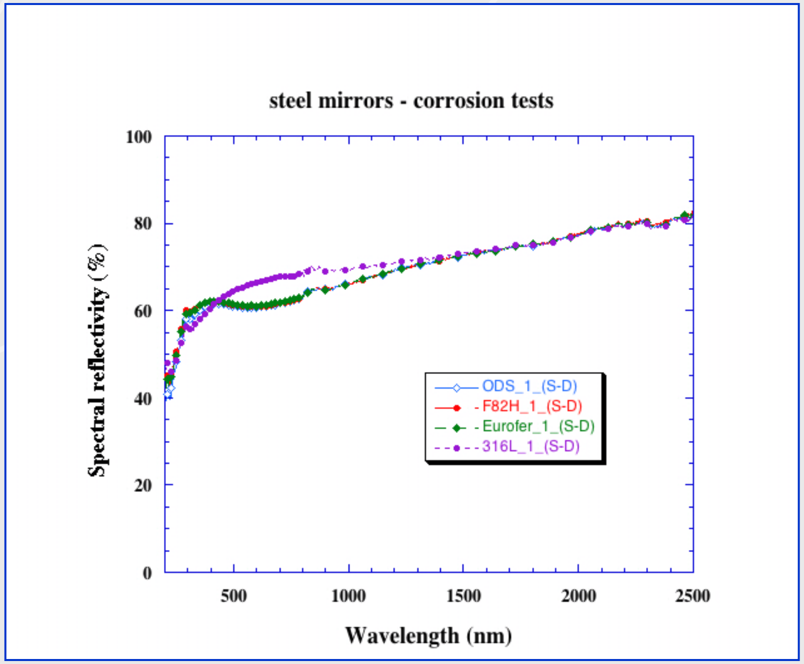
SiO / SiO_2 ratio ==> swelling cracking corrosion (LOCA)



Work on steel mirrors prepared from 316, F82H, Eurofer, and Eurofer ODS

Gamma irradiations at 170 ºC to about 50 MGy underway (N_2 atmosphere)

Then examine corrosion resistance due to irradiation in humid atmosphere

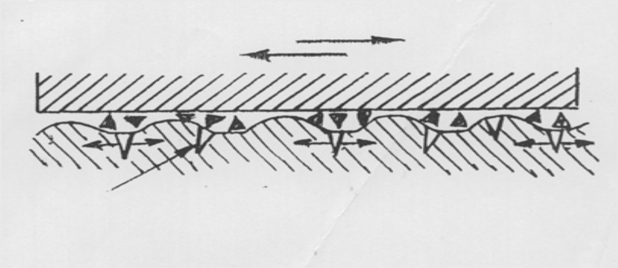


Investigations at ISSP Chernogolovka (Russia)

Compiled by N. Klassen

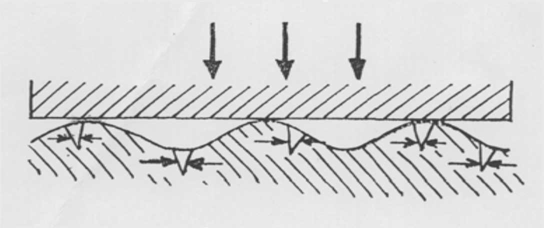
Institute of Solid State Physics,
Russian Academy of Science,
Chernogolovka.

Anti-adsorption effect of deformation polishing



Usual abrasive polishing

Abrasive polishing due to tensile stresses produces microcracks, microscratches and other defects, working as adsorption centers for various surface contaminants

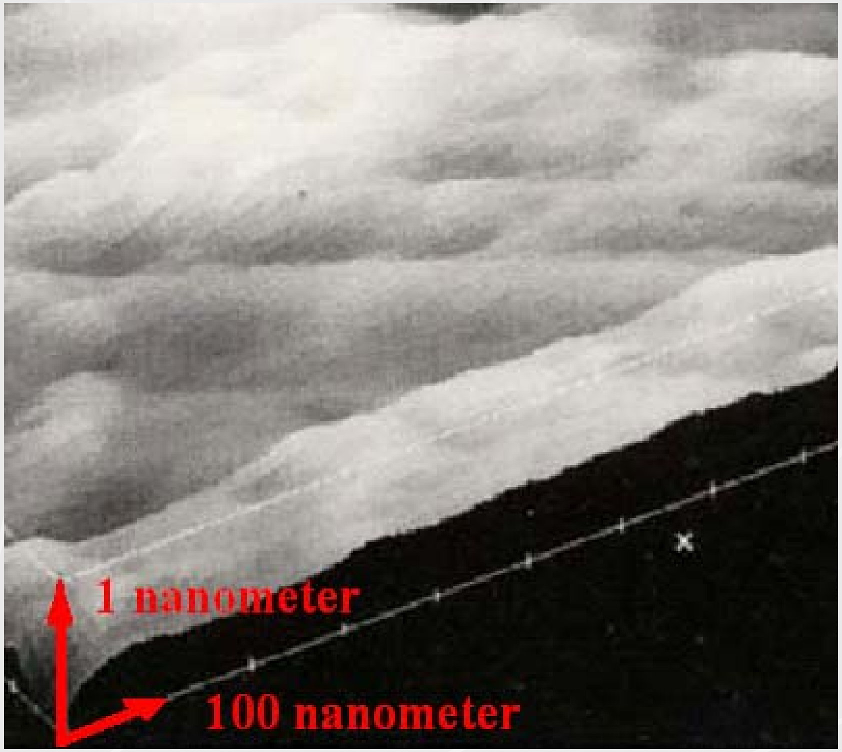


New process of deformation polishing

Deformation polishing due to compressive stresses does not produce surface defects thus eliminating all centers of adsorption

Institute of Solid State Physics,
Russian Academy of Science,
Chernogolovka.

Surface of coatings



Typical atomic force micrograph of surface of aluminium mirror after deformation polishing. The roughness does not exceed 3 nanometers. The rate of adsorption of chemical contaminations is decreased by many times due to absence of adsorption centers.

Maximum available mirror size: ~ 40 mm

Investigations at ASIPP (China)

Compiled by J. Chen

First Mirror Experiments in HT-7

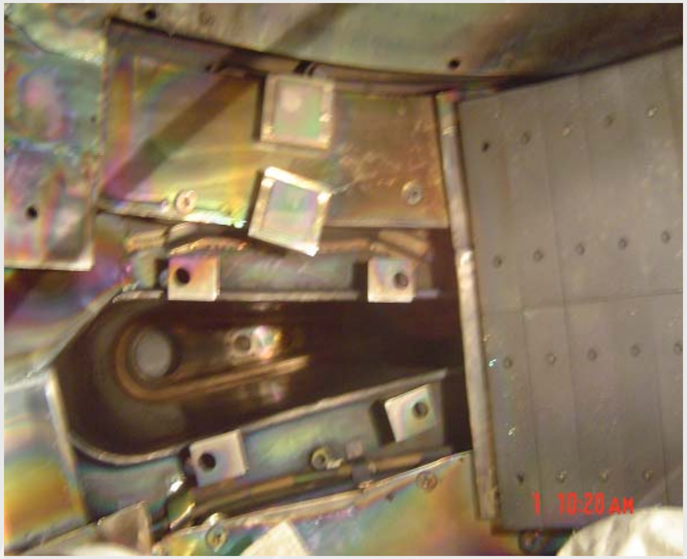
ASIPP

EAST

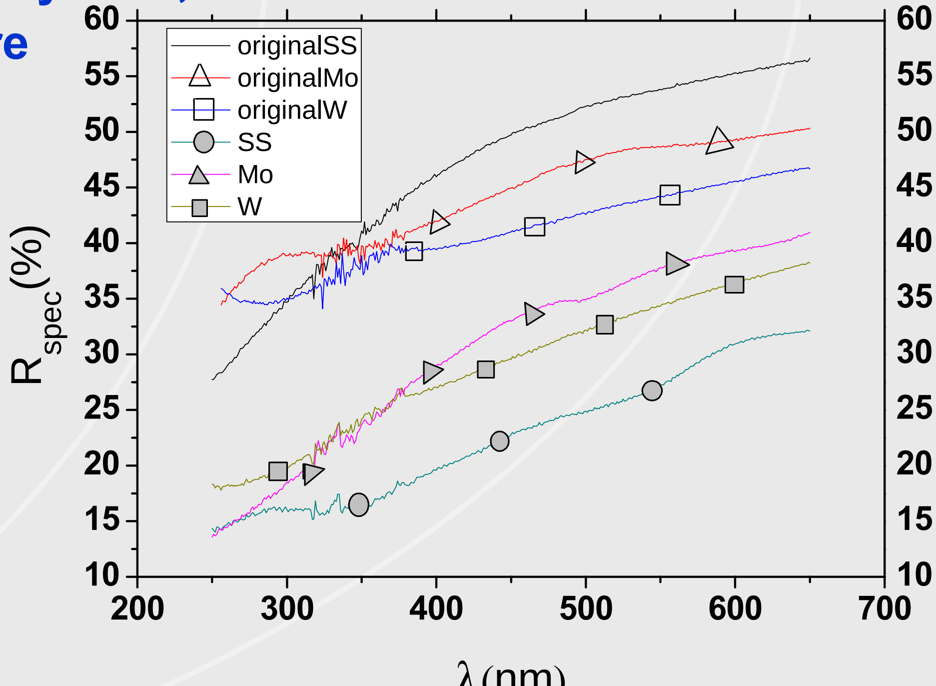
Erosion and deposition studies

2 possibilities of exposure of mirror samples:

- ► **Magnetic transport system;**
- ► **Long-term exposure**



Long-term exposure of FMs (PC-W, Mo, SS) near graphite limiter



The reflectivity was very strongly affected by erosion and deposition

First results

- ► Least change in the reflectivity of W sample, despite surface morphology change;
- ► Stronger impact on the reflectivity and surface morphology of Mo sample;
- ► The strongest effect on surface and reflectivity of SS sample.

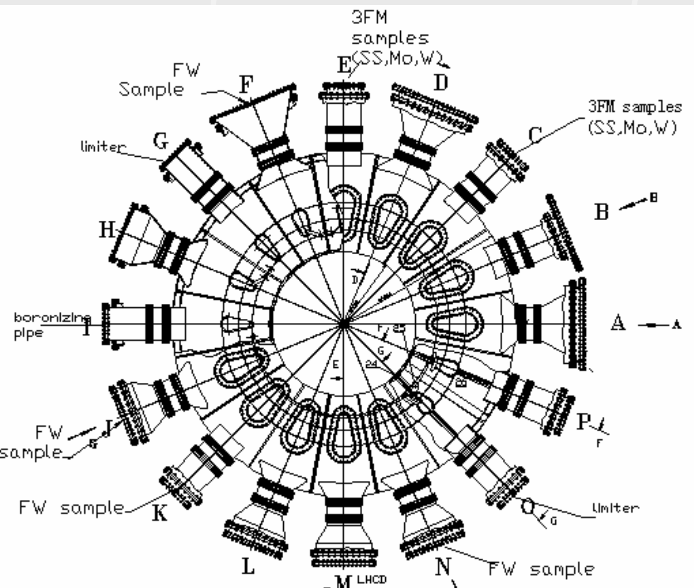
A. Litnovsky, Report of the FM SWG, 12th Meeting of the ITPA TG on diagnostics, Princeton, USA, March 28, 2007

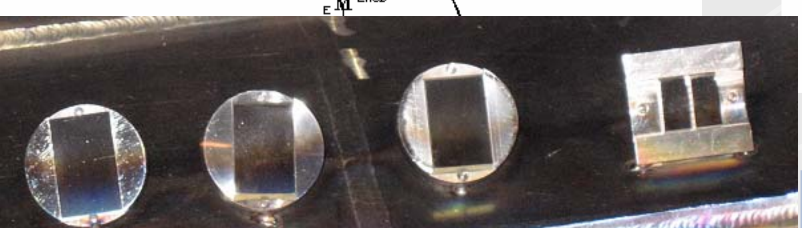
First Experiments with FMs in EAST

ASIPP

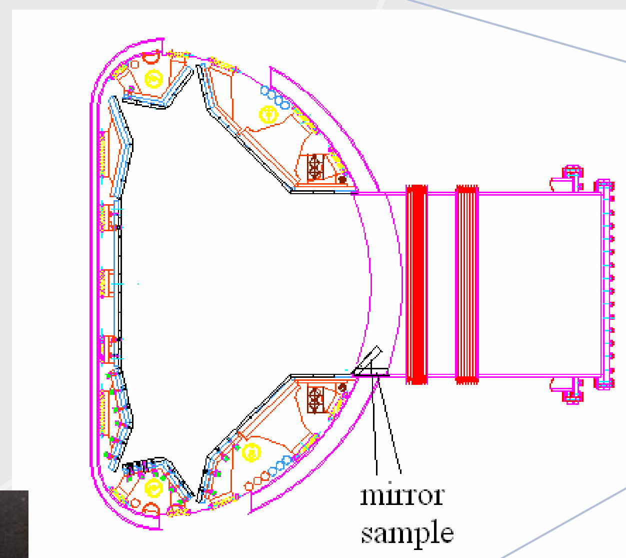
EAST

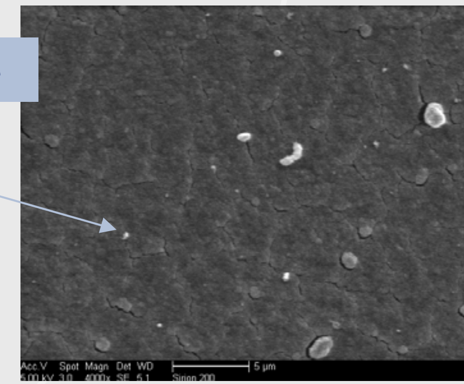
- ► mirror samples installed on the wall near the windows
- ► mirrors samples exposed during the whole campaign
- ► after exposure the color of the mirror’s surface changed
- ► the change maybe be caused by wall conditioning.

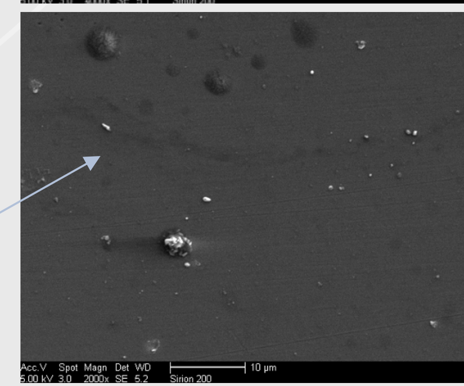




SS samples near the boronization pipe







SS samples far away from the pipe

The samples installed in different toroidal locations demonstrate very different surface morphology. The reflectivity of these mirrors haven’t been measured yet.

Summary

- ITER Diagnostic-specific research is started;
- First modeling results of ITER FMs available;
- Good progress in C deposition mitigation and cleaning;
- Research on Be deposition is intensified;
- More institutions and laboratories involved.

Thank you