First Mirror Unit and Large-Scale Collecting Mirror Conceptual Designs for ITER Optical Diagnostics

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1 author:

Dmitry Samsonov
Ioffe Physical Technical Institute

First Mirror Unit and Large-Scale Collecting Mirror Conceptual Designs for ITER Optical Diagnostics

D. Samsonov[1], N. Babinov[1], I. Bukreev[1], A. Chironova[1], A. Dmitriev[1], V. Filimonov[1], A. Koval[1], A. Litvinov[1], E. Mukhin[1], A. Razdobarin[1], I. Tereschenko[1], L. Varshavchik[1], P. Zatilkin[1], L. Snigirev[1], G. Marinin[2], D. Terentev[2], A. Kamshilin[3], A. Borisov[4], V. Khripunov[4], A. Gubal[5], V. Chuchina[5], I. Komarevtsev[6], V. Modestov[6], L. Buslakov[6], I. Kirienko[6], V. Lavrova[6], I. Loginov[6], P. Chernakov[7], A. Bazhenov[1], An. Chernakov[1], Al. Chernakov[1], D. Elets[1], B. I. Khodunov[1], G. Kurskiev[1], K. Nikolaenko[1], V. Senichenkov[1], V. Solovei[1], S. Tolstyakov[1], N. Zhiltsov[1], A. Mokeev[8], P. Andrew[9], M. Kempenaars[9], P. Shigin[9], L. Moser[9], R. Reichle[9], M. Walsh[9], Yu. Kapustin[10], E. Drapiko[10]

[1] Ioffe Institute, St.-Petersburg, Russia, 194021
[2] RUSSIAN TECHNOLOGIES, St.-Petersburg, Russia, 195279
[3] High Frequency Power, Voronezh, Russia, 394030
[4] NRC Kurchatov Institute, Moscow, Russia, 123182
[5] Institute of Chemistry, St.-Petersburg State University, St.-Petersburg, 199034
[6] Peter the Great St.-Petersburg Polytechnic University, St.-Petersburg, Russia, 195251
[7] Spectral-Tech, St.-Petersburg, Russia, 194021
[8] Institution 'Project Center ITER' RF DA, Moscow, Russia, 123182
[9] ITER Organization, St. Paul Lez Durance Cedex, France, CS 90 046, 13067
[10] Fusion Centre, Moscow, 123182

e-mail: d.samsonov@mail.ioffe.ru

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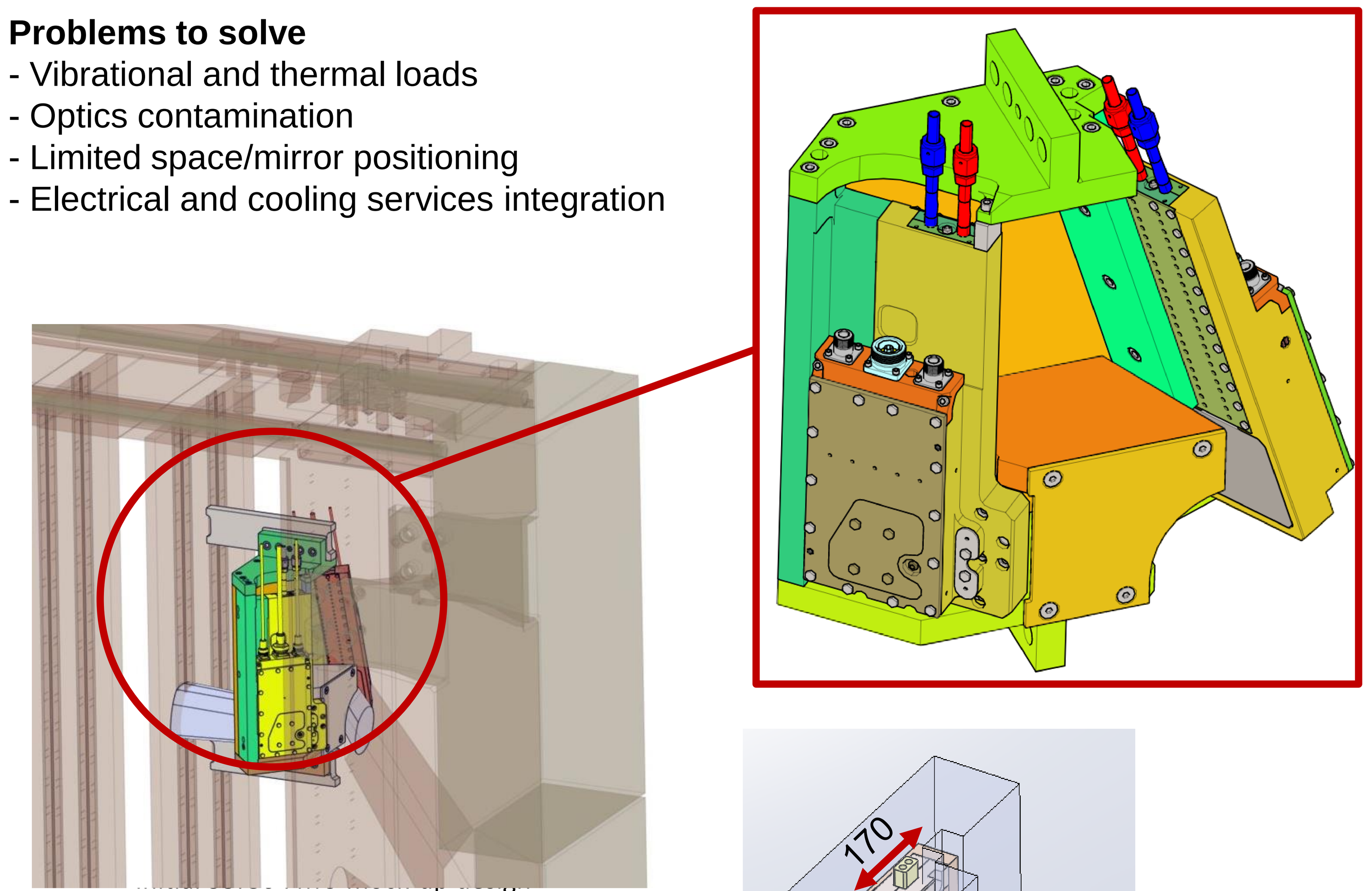
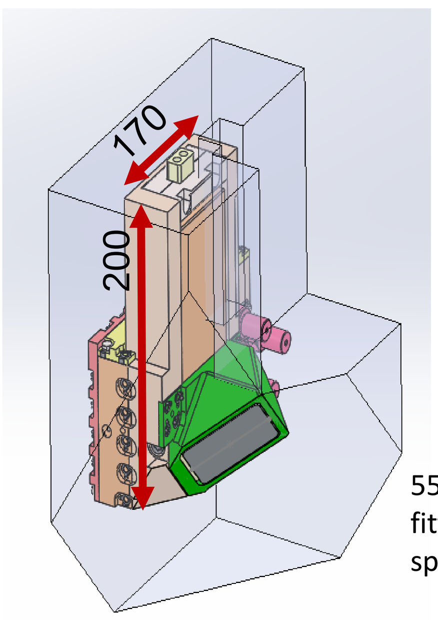
Design of FMU Mock-up for ITER

Problems to solve
- Vibrational and thermal loads
- Optics contamination
- Limited space/mirror positioning
- Electrical and cooling services integration





55.G6 FMU Mirror M1 fitted inside updated space reservation

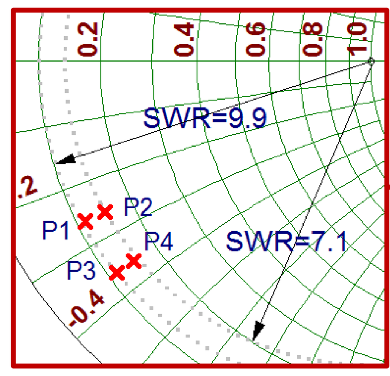
Design highlights
- Periscopic mirrors (1st and 2nd) are mounted on a common base
- Equipped with RF mirror cleaning system
- Water-cooled, DC grounded mirrors
- All-metal housing
- Possibility demonstrated to fit the mirror assembly inside compact space reservation

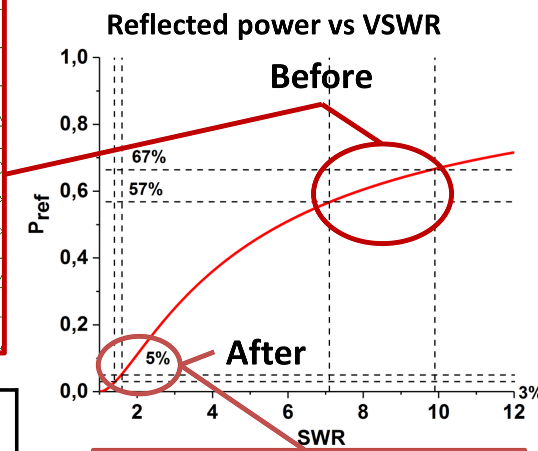
RF Power Distribution in the FMU Mirror Assembly

Problem to solve
- RF plasma load impedance depends on pressure and absorbed power
- Without matching, the reflected RF power stays 57…67% (VSWR 7.1…9.9) for 100x50 mm mirror.
- RF pre-matching required to minimize loading of the RF feeder with reflected power

Requirements to ITER in-vessel RF matchbox
- Should be as close to the load as possible to minimize load on the RF circuit inside FMU
- Should be as simple as possible. Ideally - should not contain tunable elements

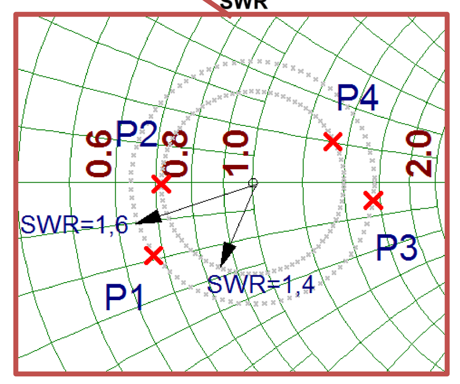
Implementation details
- Distributed LC-equivalent pre-matching circuit
- Planar arrangement, stacked AlN substrates
- Shape of matching elements was optimized to simplify the design
- Provides <5% reflected power (VSWR 1.6)



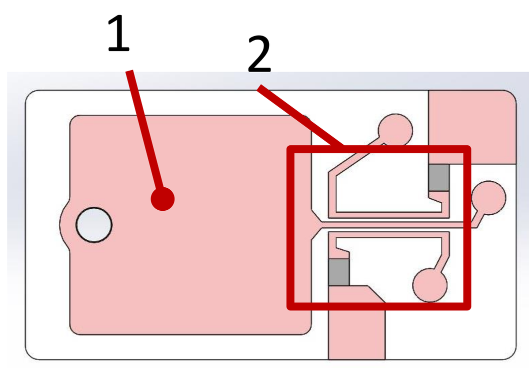


Pt. #	Re(Z) Ω	Im(Z) Ω
P1	5.7	-13
P2	7.5	-13
P3	5.7	-18
P4	7.5	-18

$|Z| = 14.2 \ldots 19.5\ \Omega$



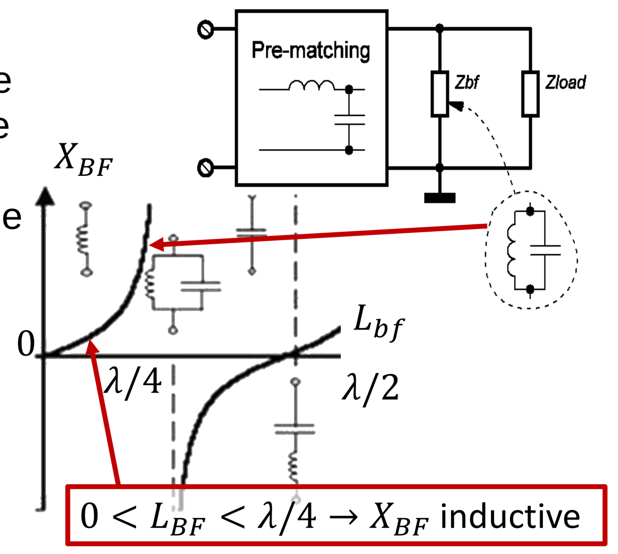
Measured RF discharge impedance and VSWR for 100x50 mm mirror



1 – Distributed matching circuit;
2 – Reflectometer

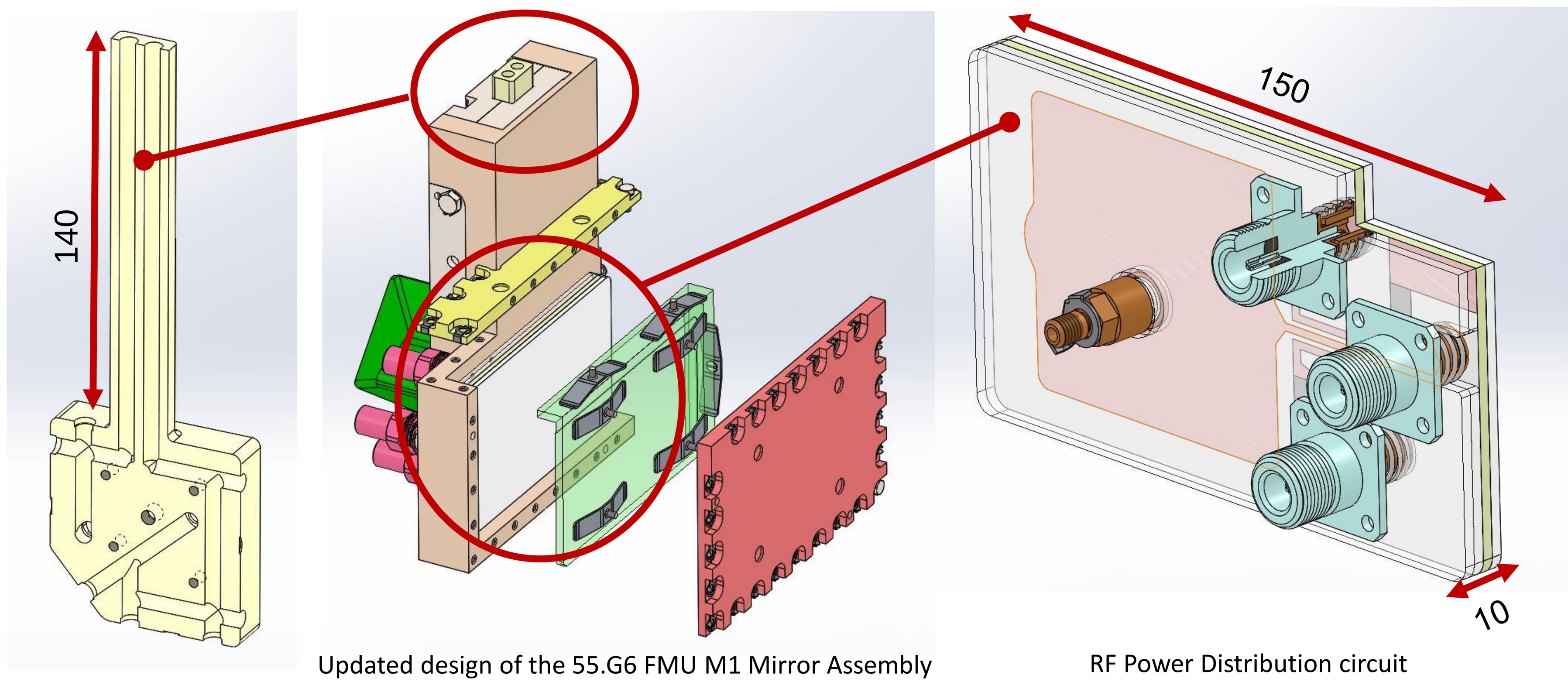
Planar RF distribution circuit outline for 55.G6 FMU

Band-stop filter design
- For cooled and DC grounded mirror, the band-stop filter impedance Zbf enters the circuit in parallel with plasma load impedance Zload. Being tuned ideally, the band-stop does not influence the rest circuit (|Zbf|→∞).
- Being tuned not ideally (<λ/4), it still works as RF-decoupler, but introduces some additional impedance to the RF circuit, allowing however, to reduce dimensions.



Design of FMU Ceramic RF Components

Problems to solve
- Brittle ceramic elements should survive thermal expansion, swelling and vibrational loads
- Ceramic elements dimensions should be minimized, and the fixture shape should prevent acoustic resonances and stress concentration
- Commercially available ceramic components are preferable



Updated design of the 55.G6 FMU M1 Mirror Assembly

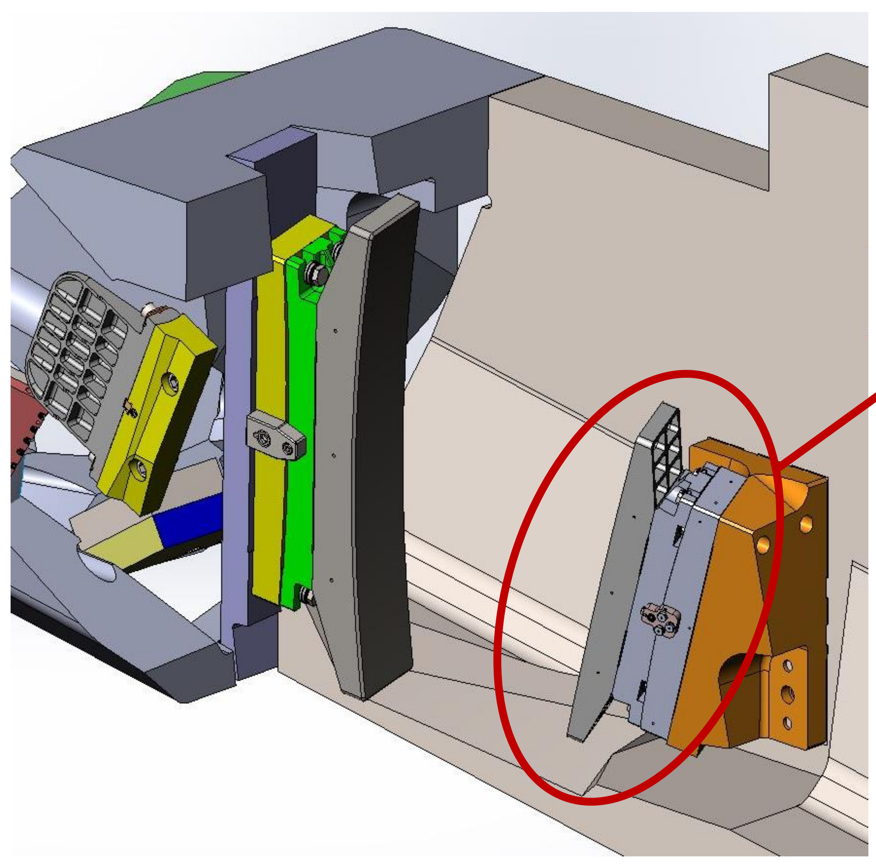
RF Power Distribution circuit

Design highlights:
- To reduce the required volume, the RF power distribution circuit is arranged as stacked ceramic plates with high dielectric permeability. Ceramic plates are fixed in the housing by flat springs through an angle clamp. The springs act independently in three directions.
- The dielectric in the band-stop filter is designed using the same approach.
- To simplify the component certification as SIC-1, the cooling channels in the band-stop filter are designed in one piece with the cooled mirror base, using deep drilling technology.
- Electrical connections to the ceramic plates are made using clamps with a tuned force.

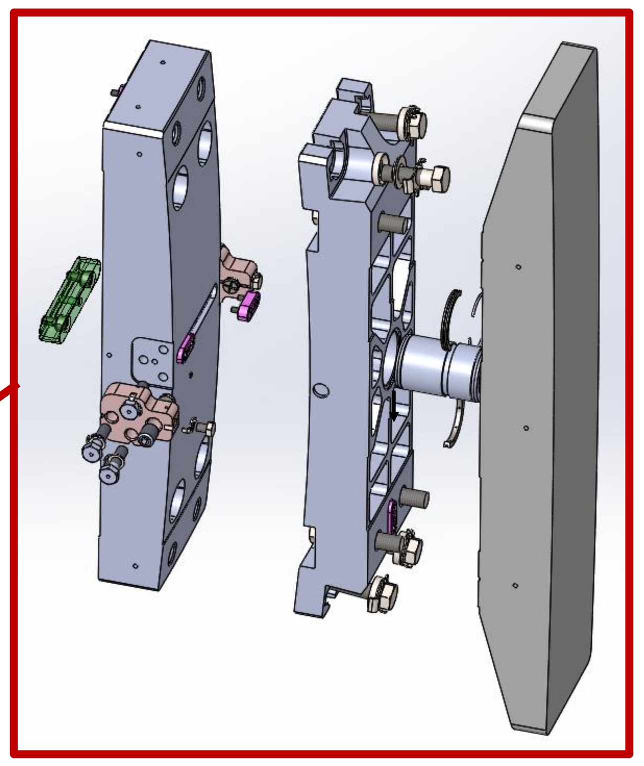
Large-scale Collecting Mirror Design of SS316

Problems to solve
- Vibrational and thermal loads with the use of SS 316 for the mirror substrate
- Large scale within limited space
- Adjustment of angular position in place

Design highlights
- Rigid design ensures alignment hold after installation
- Large base surface area ensures reflective surface shape retention
- Mirror thermal expansion matches the diagnostic rack expansion



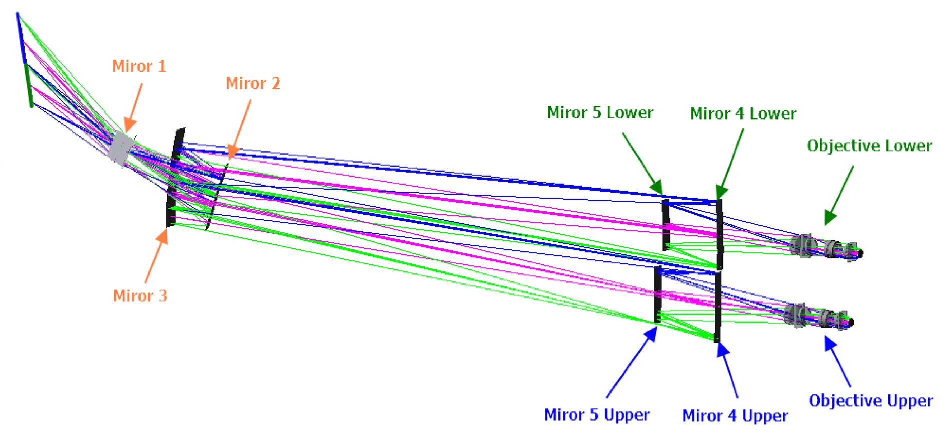
55.C4 In-vessel Collecting Mirrors installed on the LP#8 diagnostic rack



55.C4 In-vessel Collecting Mirror Design

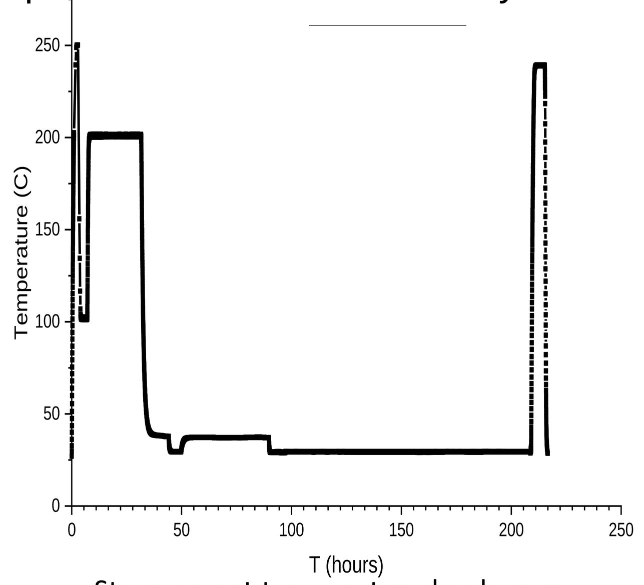
Durable Reflective Coating for 55.C4 In-vessel Mirrors of SS316

Problems to solve
- Optical layouts typically have 3..5 in-vessel reflections. To preserve acceptable total transmission, the reflectivity of a single mirror should be >90% - e.g. optic transmittance for laser diagnostics determines requirements to laser energy.
- Non FMU mirrors should perform high reflectivity being subject to cyclic thermal loads and steam ingress event.
- Typical mirror materials like Al and SS loose reflection significantly after steam exposure [1]. Bulk Rh initial reflection stays about 0,8 after steam, but Rh coatings still degrade.



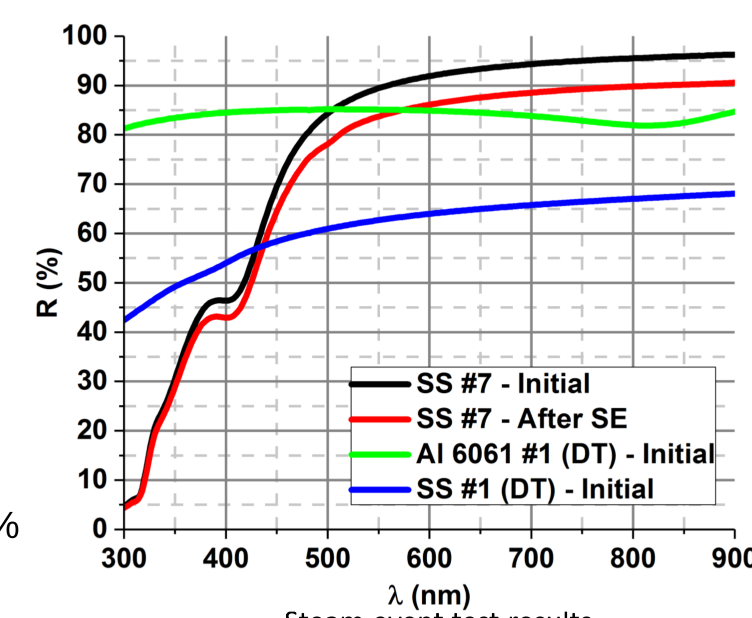
55.C4 In-vessel Collecting Optic layout

Ag reflective coating for ITER in-vessel mirrors
- New approach proposed, considering Ag reflective layer (~150 nm) protected by transparent multilayer coating (<100 nm), resistive to different corrosion agents deposited while steam ingress event: S, Cl, O [2].
- The possibility of thin Ag films in-vessel application is confirmed as a result of activation analysis of the 300 nm Ag layer over 3 cm SS substrate [3]. Induced radiation from thin Ag reflective layer is many orders lower that from SS substrate. The volatile radioactive species like Cd are blocked by dielectric coatings used for Ag protection.



Steam event temperature load curve

Steam ingress & heating test result
- The protecting coating is Si3N4/SiO2 corrosion protective layers stack. All layers were deposited with RF magnetron sputtering.
- Sample SS mirrors ∅20 mm were exposed to water steam with the pressure/temperature loading curves equivalent to ~15 ingress events [1, 4]. Before steam load, the samples were heated up to 350 C to simulate ITER divertor baking cycle.
- Initial reflection of the sample mirror was >90% in the wavelength range >550 nm, and remained >85% after heating and steam loads, which is better than initial reflection of bare metallic mirrors.



Steam event test results

Conclusion & Outlook

Conclusion
- First Mirror Unit (55.G6) initial mock-up designed and manufactured
- RF power distribution circuit developed to enable RF pre-matching of DC-grounded mirror
- Design of ceramic elements fixation developed, structural analysis performed
- Large-scale in-vessel mirror design developed for 55.C4
- High-reflective coating for collecting mirror developed, initial steam test showed promising performance

Outlook
- Perform vibrational and thermal test of the 55.G6 FMU mock-up with ceramic components
- Understand the reason of the reflectance degradation, repeat steam test with improved coating
- Scale the coating process to large-scale mirrors
- Manufacture and test the 55.C4 DTS mirror prototype

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