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Numerical analyses and loss tangent measurements for the W7-X ECRH gyrotron diamond output windows

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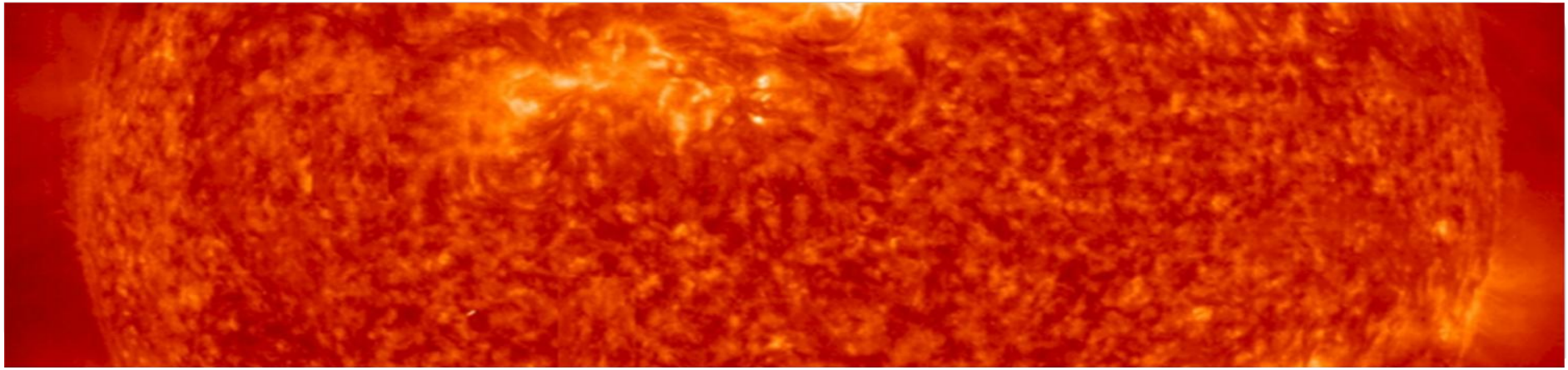
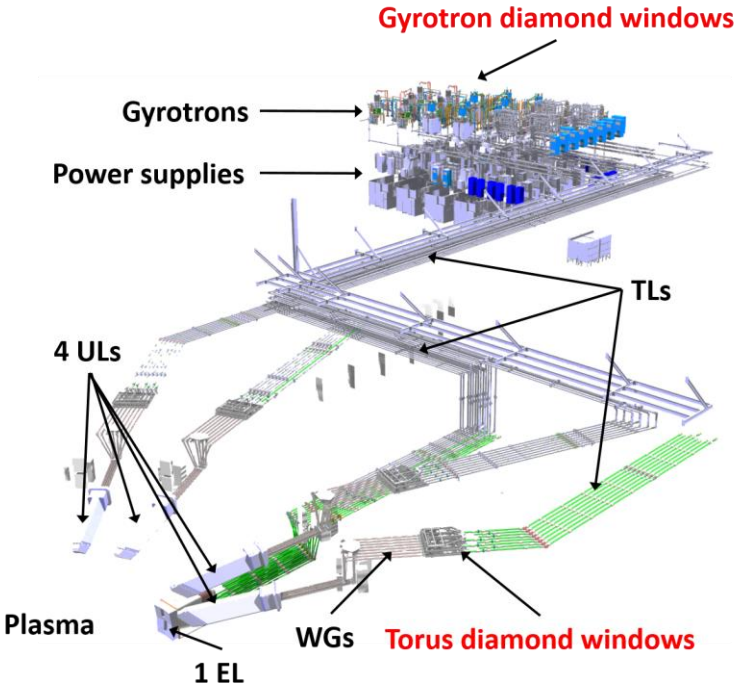
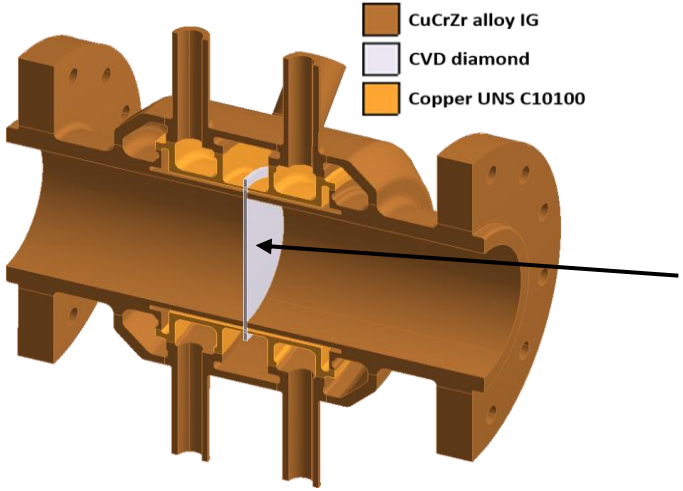


Outline

- Context
- Loss tangent measurements in diamond
- Design of W7-X gyrotron diamond output window
- Numerical analyses for 1.5 MW operation
  - CFD conjugated heat transfer with water and oil
  - Parametric
  - Structural
- Summary and outlook

EC H&CD system (example from ITER)



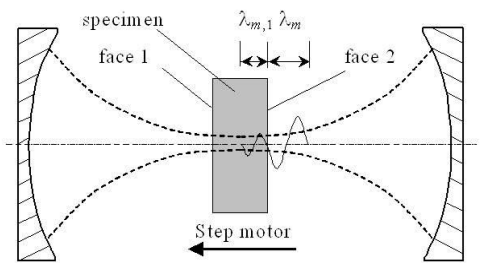


Diamond disk

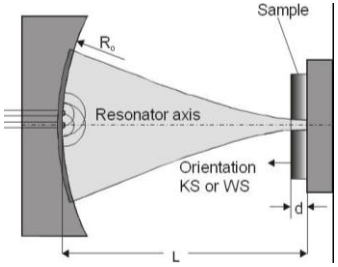
- **1 MW** beam – ITER
- **1.5 MW** beam – W7-X
- **2 MW** beam – EU DEMO

Loss tangent measurements in diamond

Spherical setup



Hemispherical setup



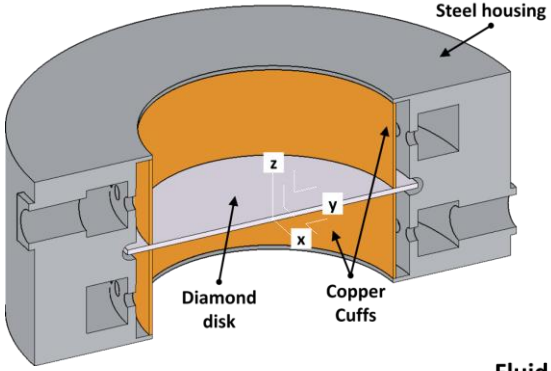
$$P_{abs} = \frac{P_{beam}\,\pi\, f\, t\, tan\delta\, (1+\varepsilon_r)}{c_0}$$

	tanδ [x 10^{-5}]	absorbed power [W]
Conservative assumption	5.68	1500
Disk 89DB1	4.55	1201
D90, average on 25 bare disks	3.49	921
D50, average on 25 bare disks	2.10	555

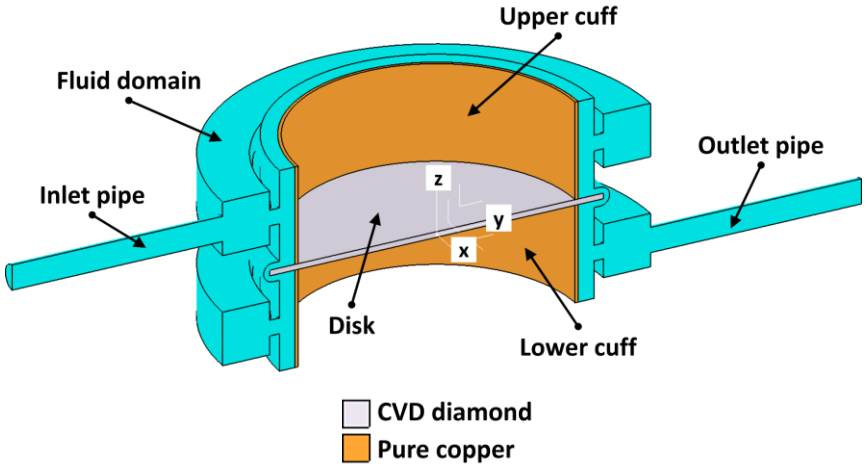
- Fabry-Perot resonators to measure the tanδ of the diamond disks
- Input to numerical analyses to model power absorption in disks
- Margin against potential degradation factors of the disk quality

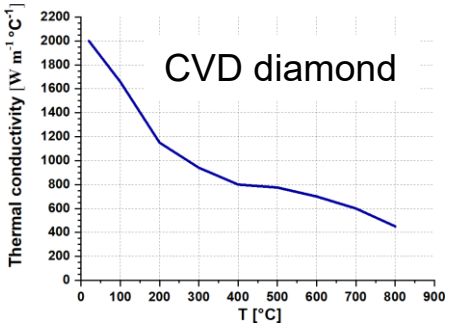
- P_{beam} = 1.5 MW
- f = 140 GHz
- ε_r = 5.67,
- t = 1.8 mm

Design of W7-X window and CFD analysis setup



$$q'''(r) = \frac{2\,P_{abs}}{\pi\,{w_0}^2\,t}\,e^{-2\frac{r^2}{{w_0}^2}}$$





- Gaussian mm-wave beam with 20 mm radius
- Symmetry
- Temperature dependent material properties
- 0.2 kg s^{-1} at inlet (25°C) at inlet and 0 Pa at outlet
- Runs with different absorbed power values
- Runs with water and silicon oil DC 200(R) 5cSt

CFD analysis results at 1.5 kW absorption

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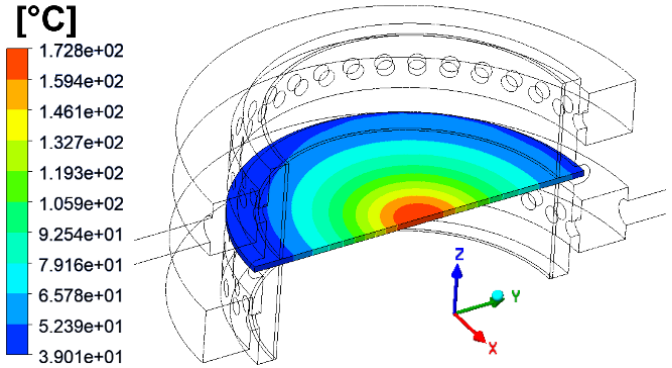
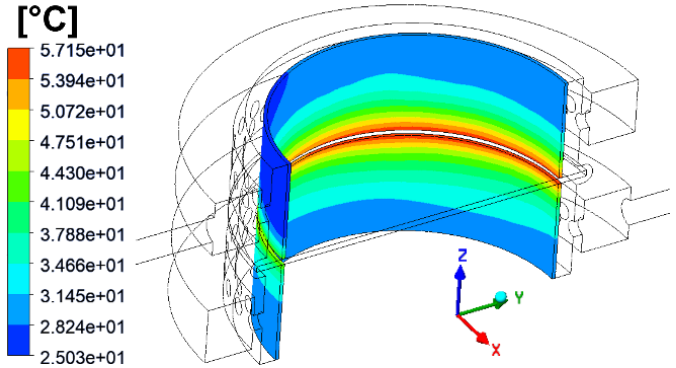
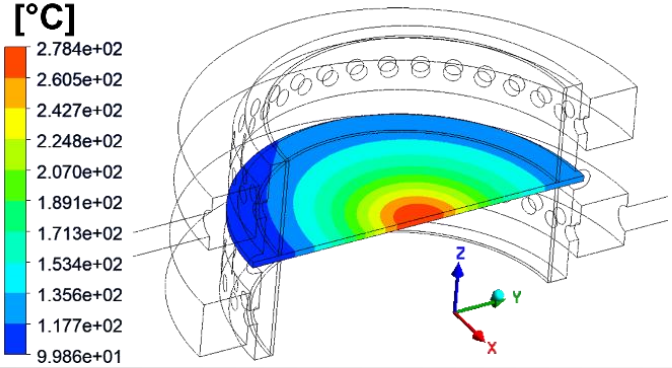
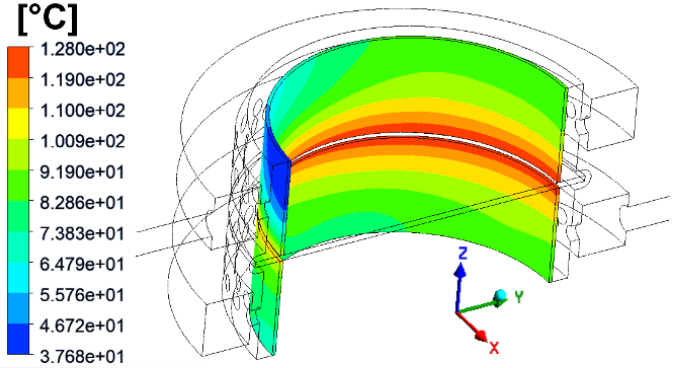
Water



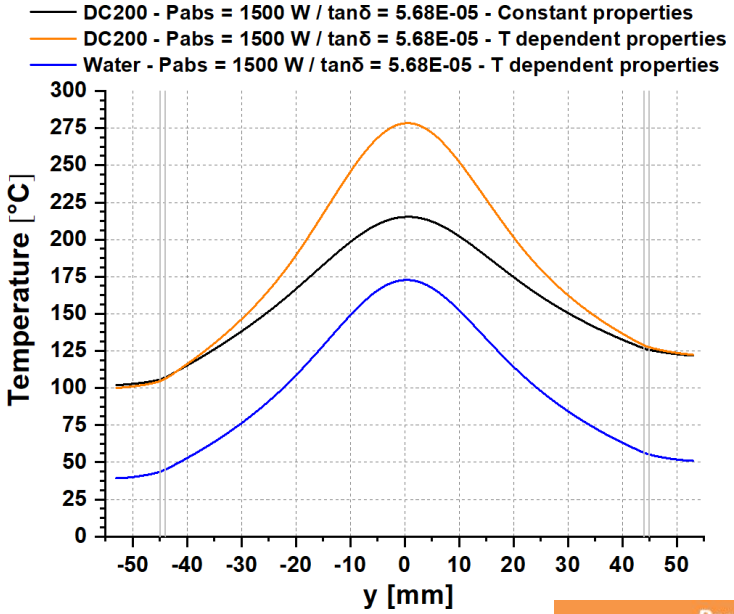


Oil (DC200)





CFD analysis results at 1.5 kW absorption

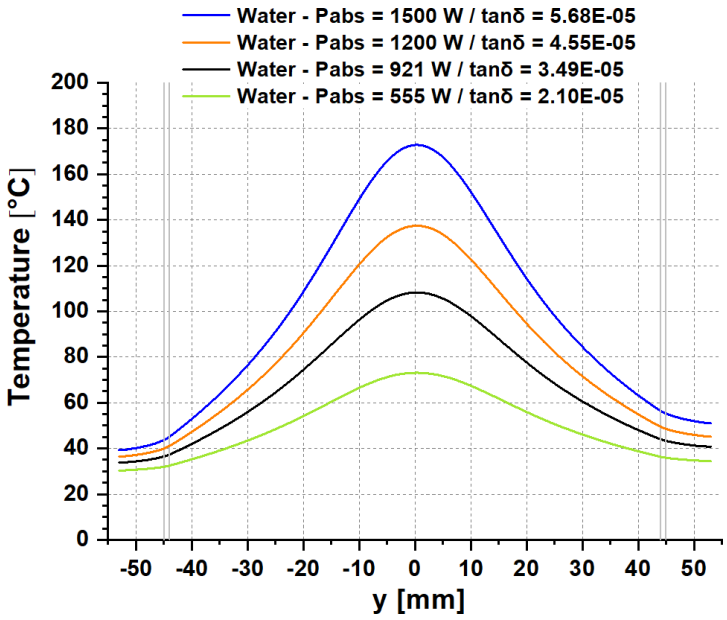


- 250°C is the limit assumed for diamond
- **Oil-cooling** is not an option for the window at 1.5 kW absorption
- **Water-cooling** shall be used at high power operations
- **Temperature dependent properties** (particularly for diamond) shall be used

	density [kg m^{-3}]	dynamic viscosity [Pa s]	specific heat [J kg^{-1} K^{-1}]	thermal conductivity [W m^{-1} K^{-1}]
Water	997	8.90 x 10^{-4}	4182	0.607
DC200	915	45.8 x 10^{-4}	1639	0.142

Coolant	*Pressure drop [bar]*	*ΔT fluid inlet-outlet [°C]*	*Max T in disk [°C]*	*Max T in cuffs [°C]*	*ΔT disk edges [°C]*	*Power fraction removed by diamond [-]*	*Power fraction removed by copper [-]*
Water	0.15	1.75	172.8	57.2	11.8	58%	42%
Oil	0.20	4.47	278.4	128.0	22.4	48%	52%

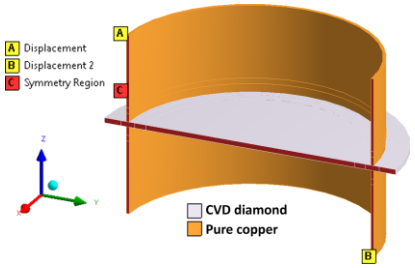
Parametric study for loss tangent



- **Water-cooling** provides by far significant temperature reserve margins, even at higher values of absorbed power
- **High reserve margins** are important to counteract potential factors leading to a degradation of the microwave transmission capability of the diamond disk

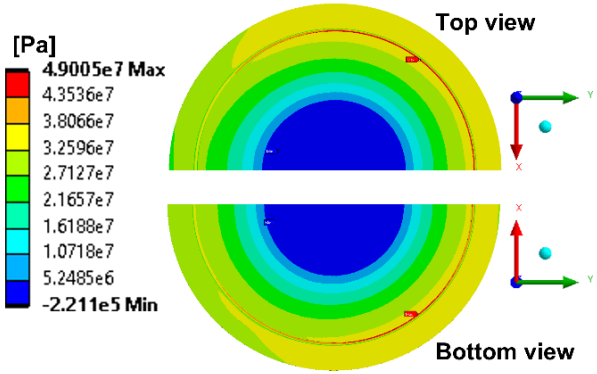
Absorbed power in disk [W]	Water		DC200	
	Max T in disk [°C]	Reserve margin [°C]	Max T in disk [°C]	Reserve margin [°C]
1500	172.8	77.2	278.4	-
1200	137.4	112.6	213.1	36.9
921.4	108.2	141.8	159.3	90.7
554.5	73.11	176.9	100.7	149.3

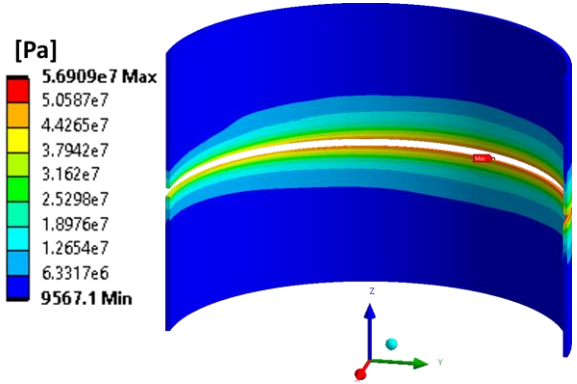
Structural analysis at 1.2 kW absorption



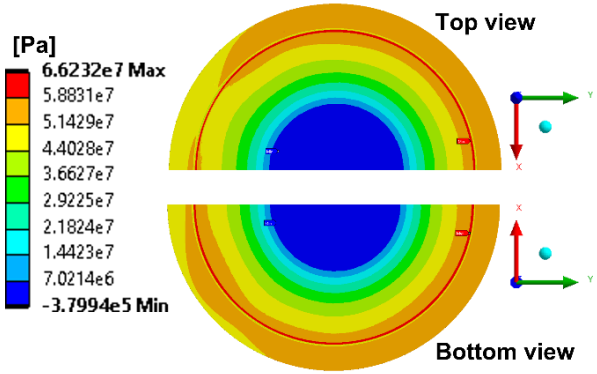
- Plastic steady-state analysis
- 150 MPa is the limit assumed for diamond
- Lower stresses in water-cooling option
- No significant changes at 1.5 kW power absorption

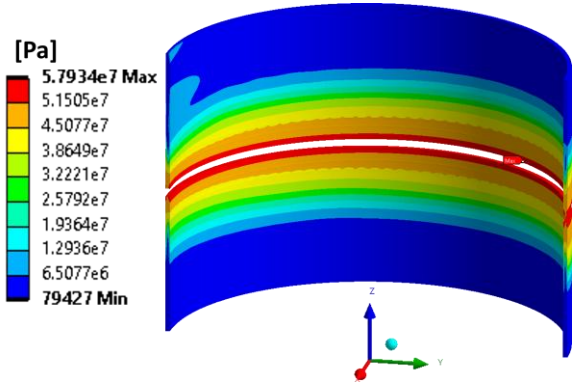
Water





Oil





Summary & outlook

- The W7-X gyrotron diamond output window was investigated by numerical analyses to assess its performance at 1.5 MW operation for water-, oil-cooling
- The water-cooling represents a much better option than oil as it leads to lower temperatures and stresses in the window, with higher reserve margins
- Temperature dependent properties shall be used to obtain a real picture of the window performance at these power levels
- The window shall be later characterized for 2 MW beam transmission

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