Loss Tangent Measurement on synthetic crystalline diamond (SCD) samples

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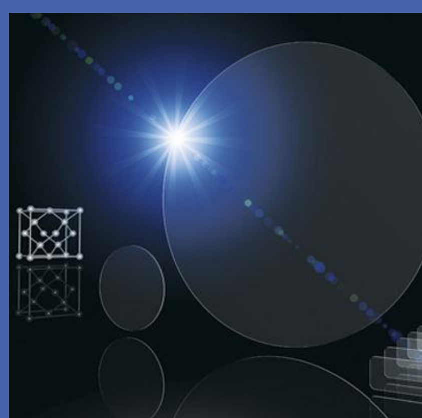

Outline

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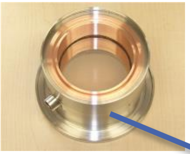
  CVD Diamond Windows
  SCD samples
- Experimental Setup
  Vertical resonator
  Double spherical resonator
  Hemispherical XY mapping resonator
- Results
- Conclusions

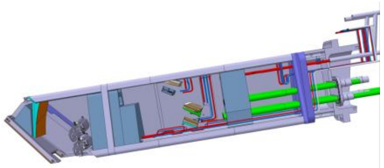
Electron Cyclotron Resonance Heating and Current Drive System

Gyrotron

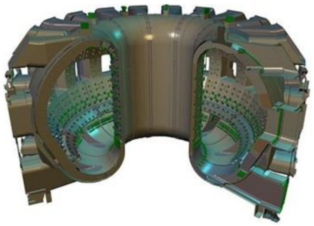
Waveguide



CVD window

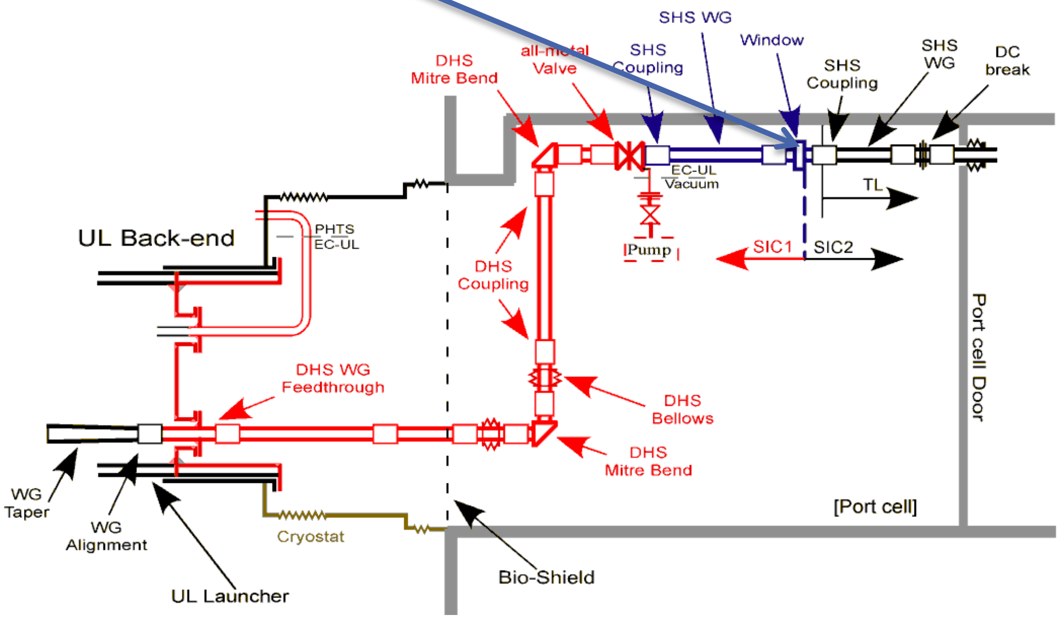


Upper Launcher



Vacuum Vessel

ECRH&CD systems are meant to heat the plasma, destroy instabilities and drive current inside the vacuum vessel of a nucleare fusion reactor



CVD Diamond Windows

Diamond windows are fixed installations of a nuclear reactor primary confinement system, containing a potentially flammable mixture if exposed to air.

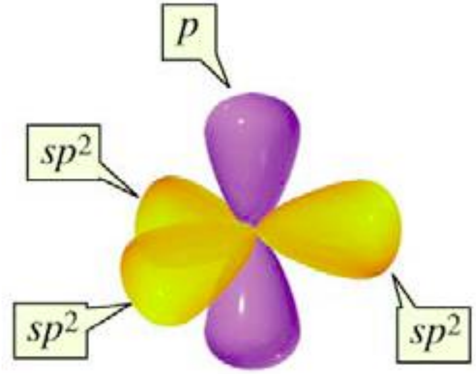
Requirement for the windows assembly include:

- Ultra low loss microwave transmission
- No dead volumes to minimize the stagnation of tritium and the pumping time.
- Full range of monitoring diagnostics (Tritium detection, microwave leakage, pressure, arc detection, temperature)

Source: Iter Tritium handbook, Iter vacuum handbook

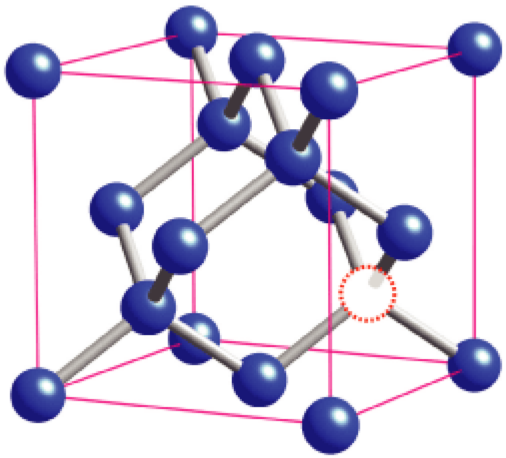
Single Crystalline Diamond

Why single crystalline diamonds ?



Policrystalline CVD diamods → bulk sp2 boundaries → electrically conductive → microwave absorption hotspots

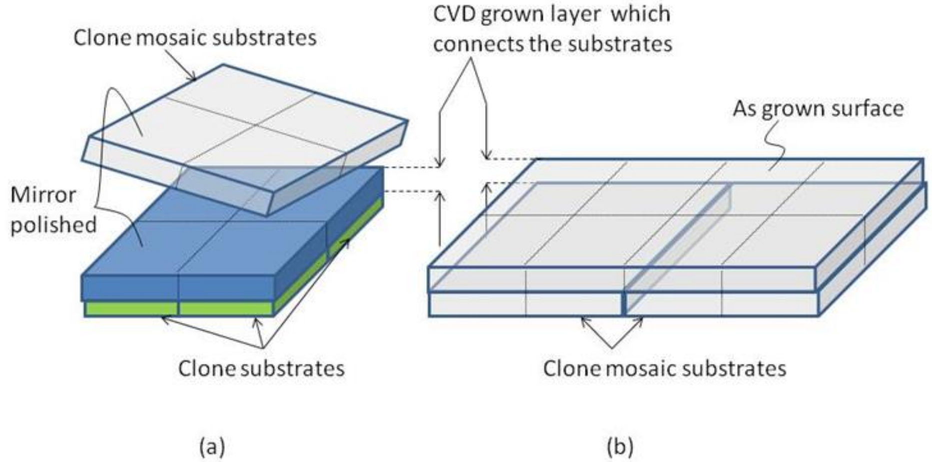
Single crystal diamonds (SCD) → sp3 bindings only → improved transmissivity

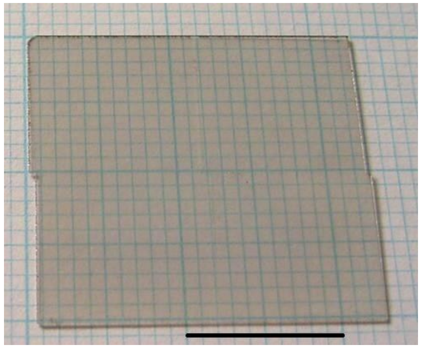


AIST SCD samples

Commercially available SCD samples are too small for fusion applications, being in the 2-3 millimeter range, while polycristalline ones are available in up to 5 inches wafers.

Dr. Yamada at AIST (Osaka, JPN) proposed a technique to compose relatively small samples of SCD into a larger size area, with sufficient quality to fabricate freestanding wafers from it.

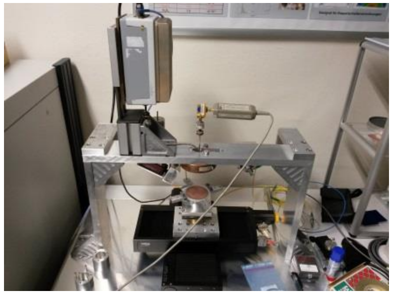




"Tiled SCD clones" technique samples in the cm range (20 mm^2) are possible.

Images courtesy of Dr. Hideaki Yamada – National Institute for Advanced Industrial Sciences and Technology (Osaka, JPN)

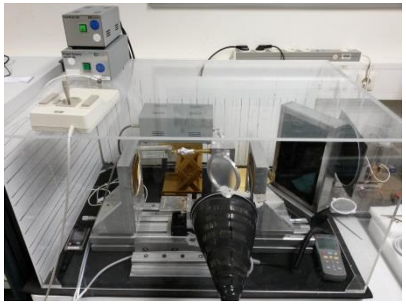
Experimental Setup



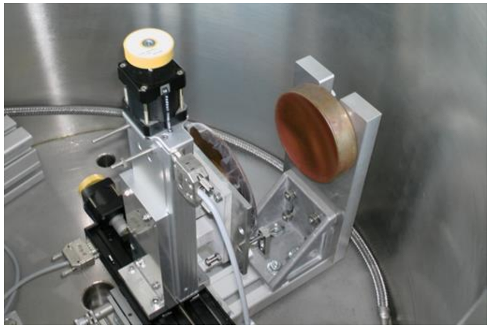
Vertical Cavity Resonator

Setup consisted in three different kind of resonators, with sources at 90 – 100, 145 and 170 GHz. Beam profile is gaussian. The double spherical resonator has a resolution in the order of 10^{-6}, while the other two attain 10^{-5}.

- The DSR is capable of shifting the sample in the Z direction → estimation of bulk and surface losses.
- Change in the inverse cavity Q-factor (with and without sample) → Loss tangent values



Double Spherical Resonator (DSR)

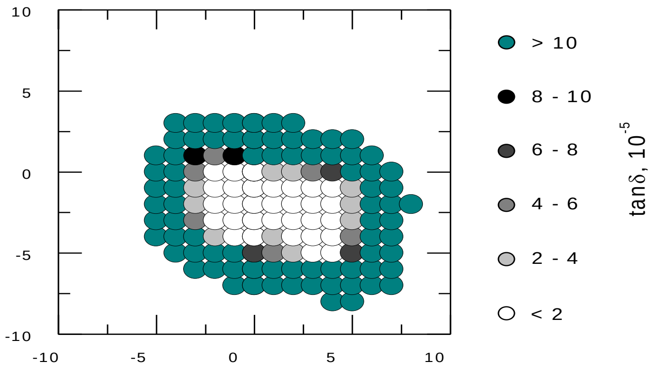


Hemispherical XY mapping resonator

Iterative solution of the resonator equation → Relative permittivity ε_r

Results: Loss Tangent

Four different AIST SCD samples where tested (thicknesses between 0.9 and 1.35 mm) and compared with a commercial policrystalline disc (PCD)



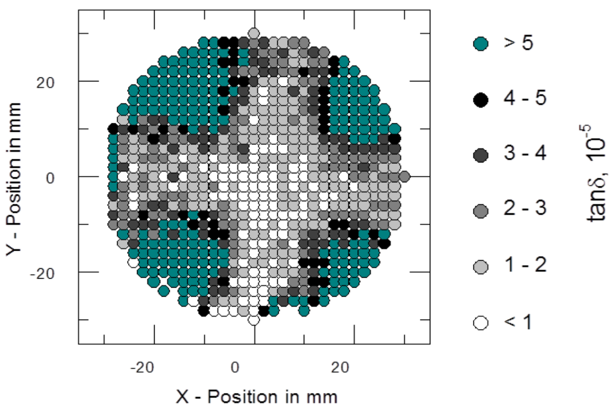
4-fold SCD reached the resolution limit of the XY mapping machine. Higher values towards the borders suggest diffraction as a cause of Q-factor degradation.

Thickness: 1.3 mm

ε_r: 5.67

Frequency: 145.07 GHz

The commercial sample shows analogous results. It is worth to be noted that while the PCD disc is polished, the AIST 4-fold samples were polished only on the growing surface



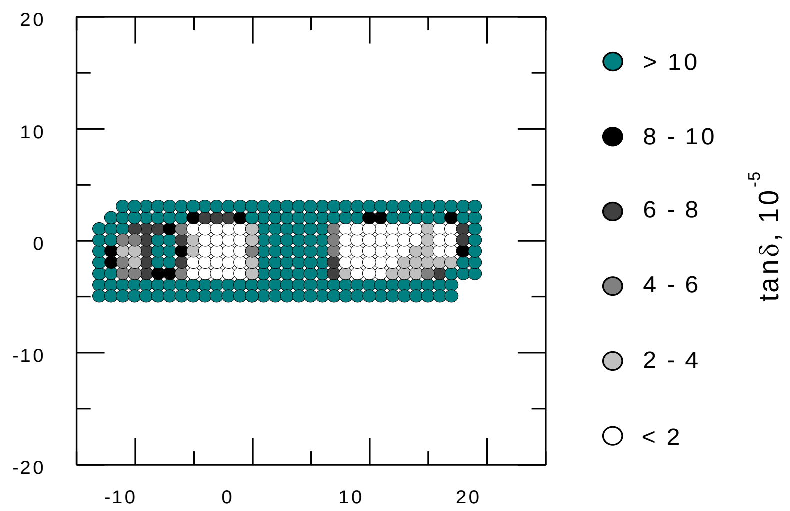
Results: Loss Tangent

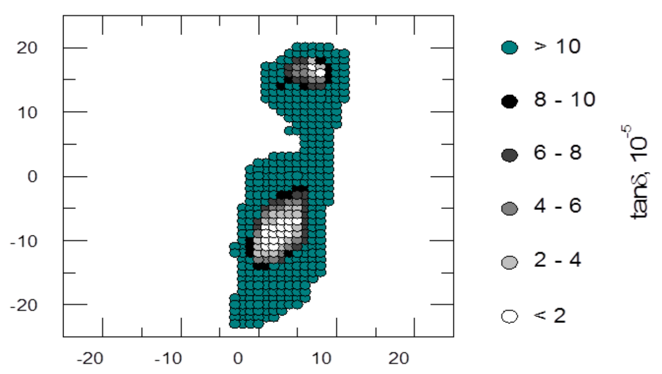
8-fold SCD unpolished → higher losses in the central region → boundary between different tiles lowers the quality

Thickness: 1.25 / 1.35 mm

ε_r: 5.67

Frequency: 145.14 GHz

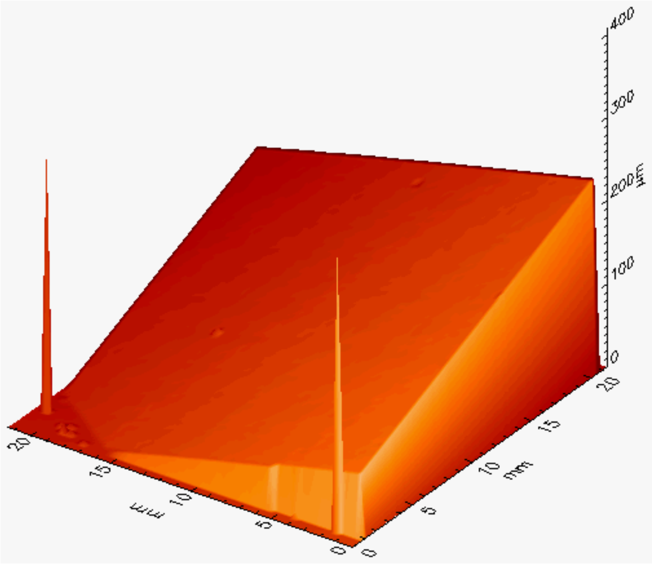




„Monodimensional“ higher losses → angular offset of the growing direction, (~ 3°) → boundary perpendicular to the growth direction = good optical quality.

(cfr. S. Ohmagari et al. / Diamond & Related Materials 48 (2014) 19–23)

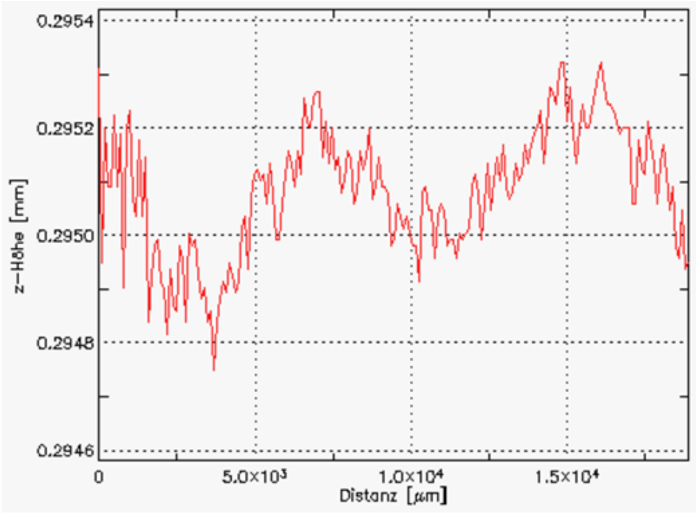
Results: Topography



Unpolished SCD sample topography

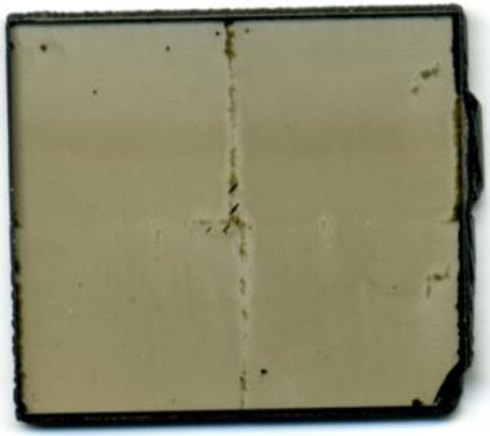
- ~ 200 µm wedge → low quality surface = bigger surface losses
- ~ 200 µm wedge → double spherical high resolution resonator measurements not good

Polished PCD sample central profile
~ 2µm max discrepancy → low surface losses (less 10^{-6} as measured with DSR)



Summary

- SCD should be able to overcome the limitations imposed by PCD bulk losses (10^{-7})
- Tiled SCD clones technique seems to be a good way to obtain cm size samples
- Performances of the SCD samples seems to be heavily influenced by growing characteristics and surface quality



THANK YOU

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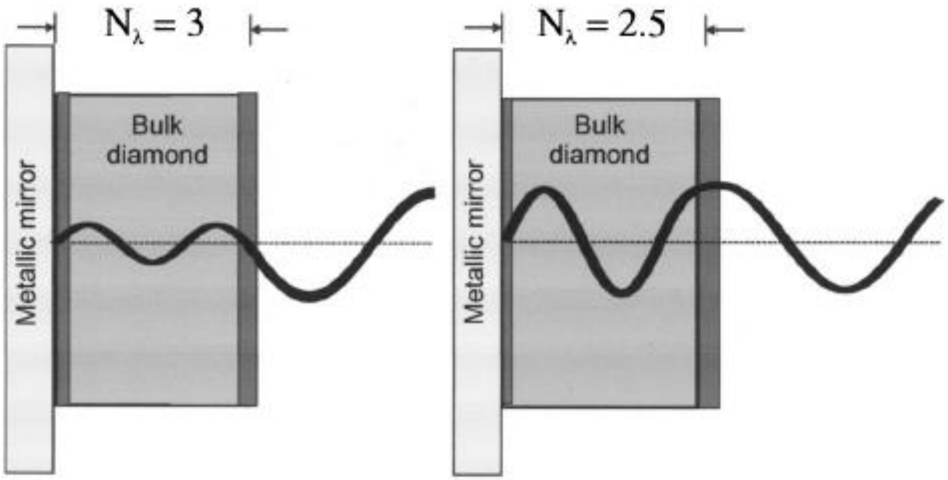
Backup Slide: Bulk & Surface Loss Tangent Calculation

$$\tan\delta = F_F(Q_1^{-1} - F_L \cdot Q_0^{-1})$$

- F_F = filling factor (effective portion of the dielectric in the resonator)
- F_L = loading factor (rescaling of stored and dissipated energy)
- Q_1 = cavity quality factor (with sample)
- Q_0 = cavity quality factor (without sample)
- N_λ = number of half wavelenghts in the sample



R. Heidinger et al., IEEE transactions on plasma science, vol. 30, no. 3, June 2002

Resonant condition = N_λ integer →
→ Node condition at the second surface →
minimum surface losses

Antiresonant condition = N_λ half integer → antinode condition at the second surface → maximum surface loss

CVD Cloned Samples preparation

1. HPHT SCD seed crystal → PECVD growt of the tiles (source gas: 90% H_2 10% CH_4)

2. Grown diamond layers are separated from the seed through lift-off process involving high speed ion beam injection. Repeating this process generates several „cloned wafers“

3. Finally, cloned tiles are put side by side in the CVD reactor. An SCD layer that connects the tiles is grown ant lifted-off, obtaining a large SCD sample.