Karlsruhe Institute of Technology

EUROfusion
POWER PLANT PHYSICS &
TECHNOLOGY DEPARTMENT

MPA CVD diamond in nuclear fusion: dielectric characterization and influence of defects

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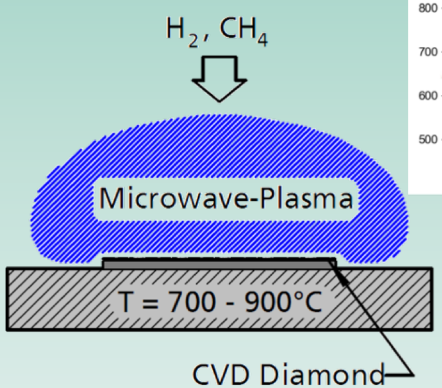
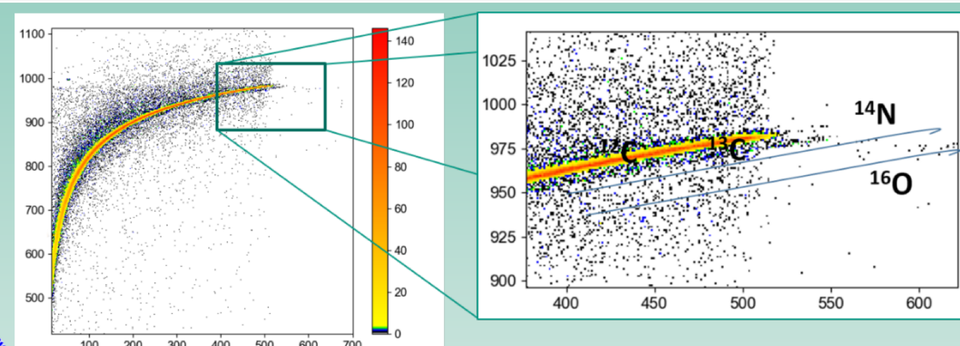
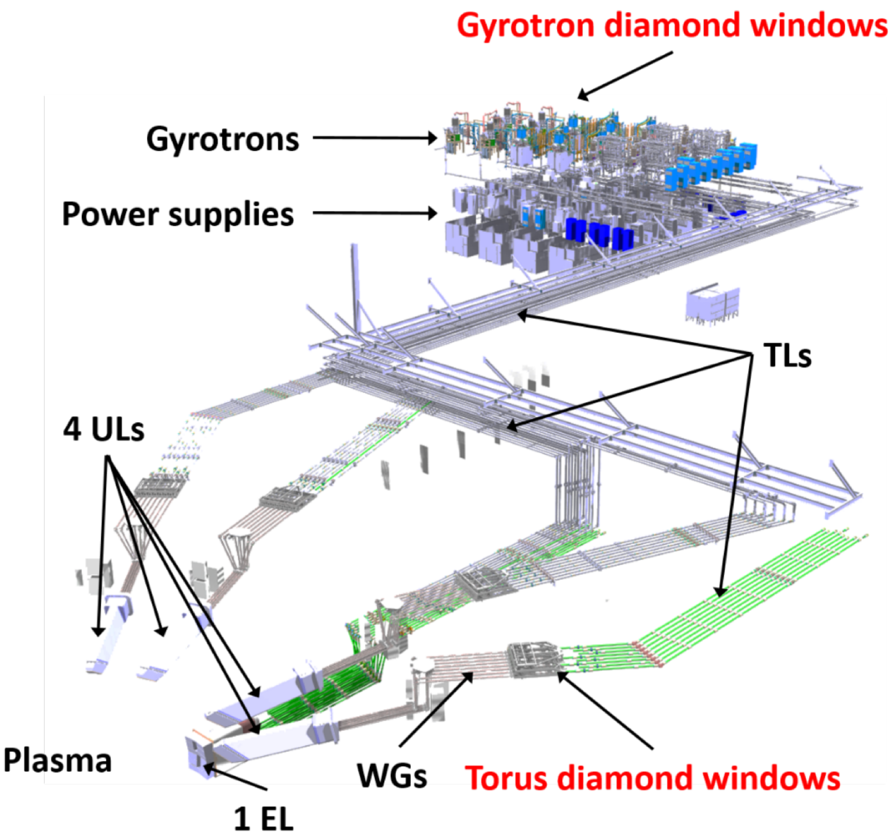


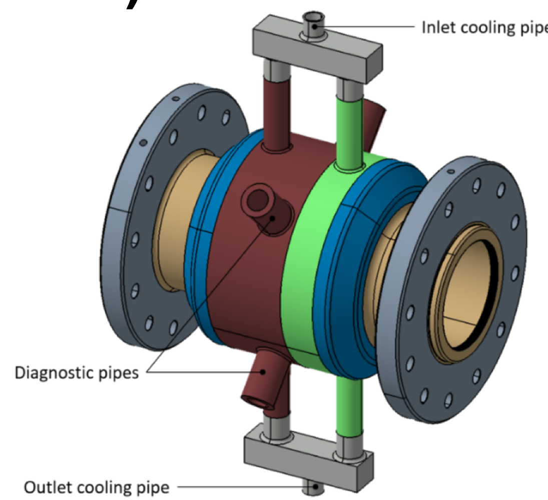


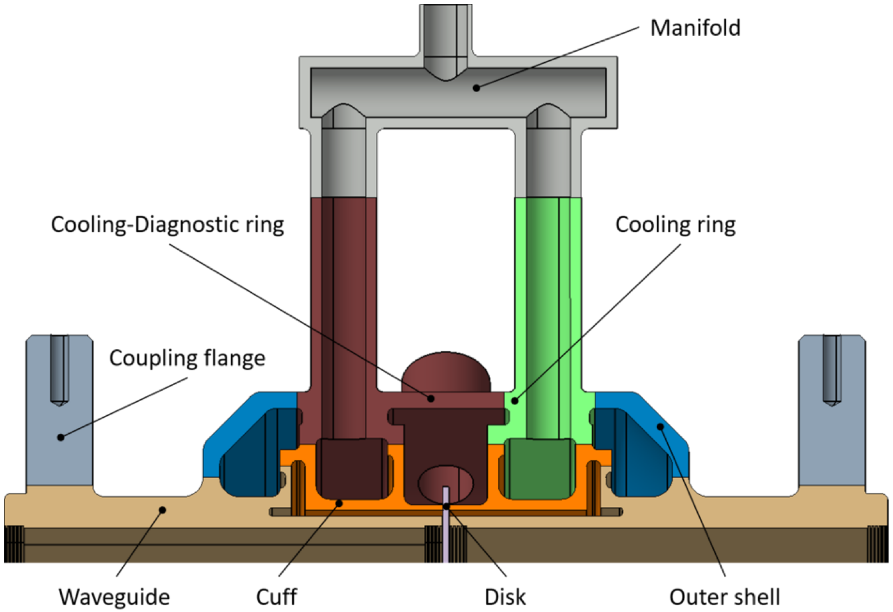
Outline

- Diamond as window material in EC HCD system (ITER)
- Loss tangent
- Diamond Brewster-angle window (DEMO)
- MPA CVD reactors
- Neutron irradiated CVD diamond
- FTIR spectroscopy
- ToF-HIERDA spectrometry
- Conclusions and outlook

EC HCD system in fusion devices (ITER)





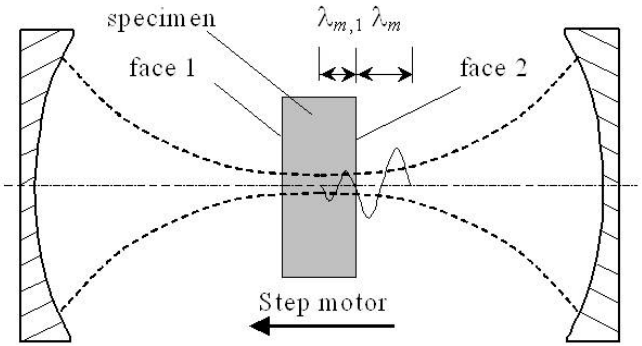


Loss tangent

- Fabry-Perot resonators are used to measure the loss tangent of the diamond disks: **tanδ**
- The measured **tanδ** is then used in the FEM analyses to model the power absorbed in the diamond disk during the beam transmission

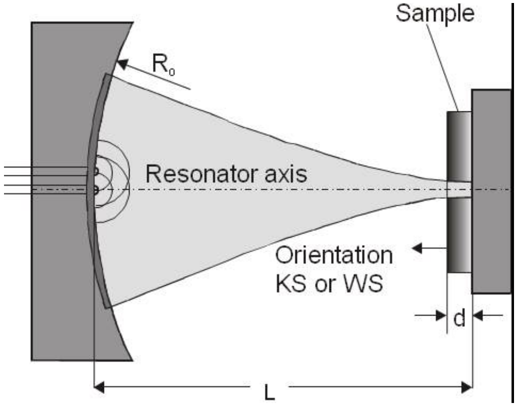
Spherical measurement setup

Determination of tanδ at the center of the diamond disk



Hemispherical measurement setup

Determination of tanδ distribution over the diamond disk surface

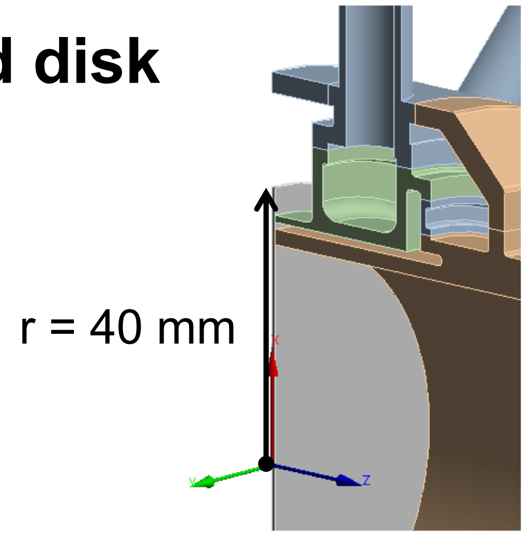


Absorbed power in the diamond disk

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

- P_{beam} = 1.31 MW (design value)
- f = 170 GHz
- ε_r = 5.67
- **tanδ = 2 × 10^{-5}**
- t = 1.11 mm

→ P_{abs} = 346 W

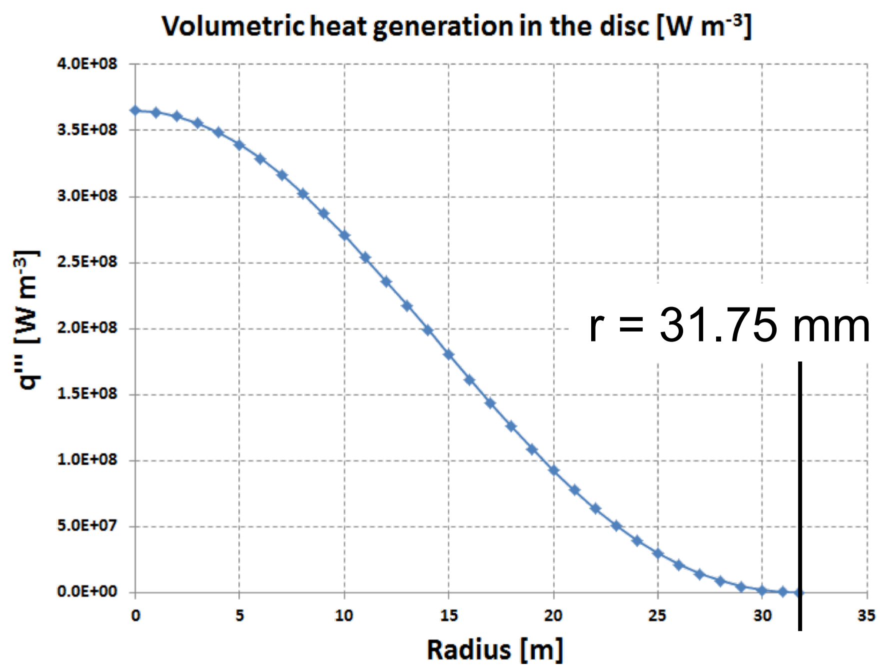


Power pattern according to HE_{11} mode beam, volumetric power density in the disk:

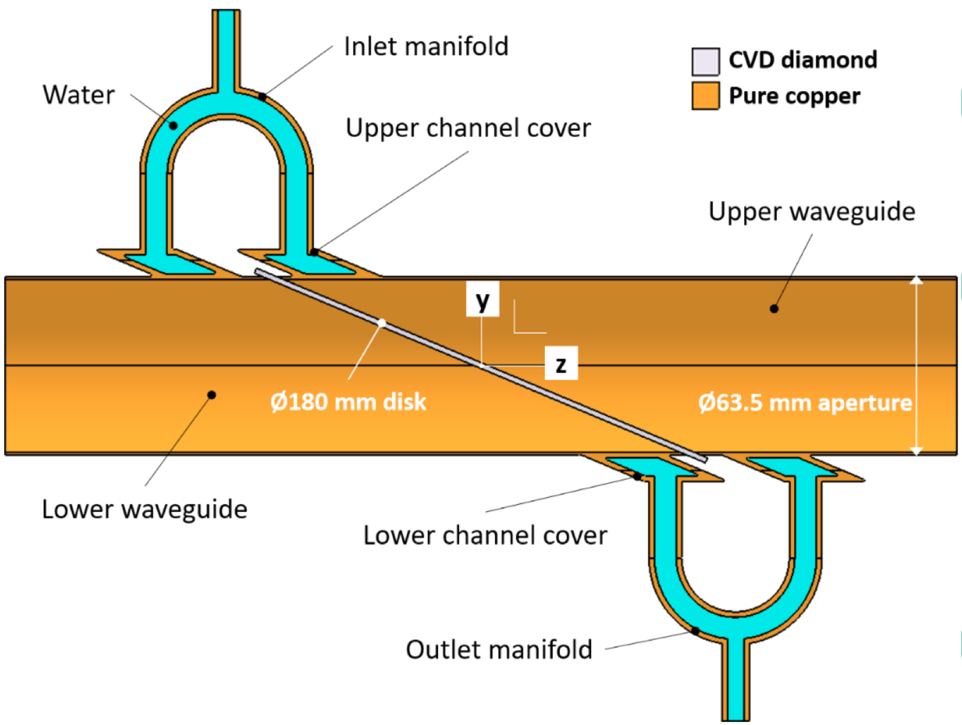
$$q'''(r) = A \cdot \left[J_0(x)\right]^2$$

$$x = 2.405 \cdot \frac{r}{a}$$

→



Brewster-angle diamond window (DEMO)

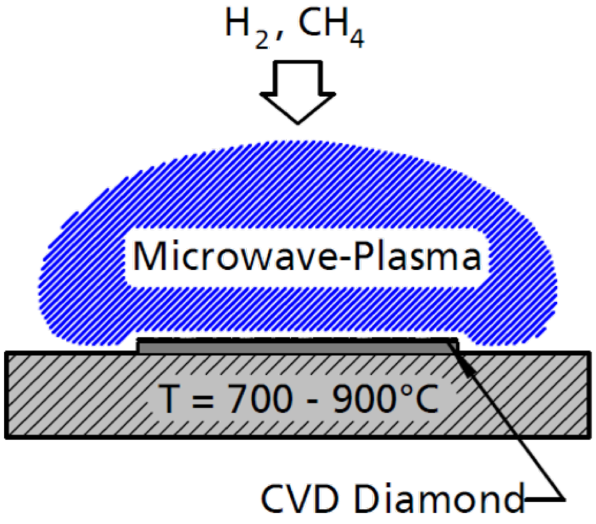


- Aperture of 63.5 mm compatible with a beam power of **2 MW**
- CVD diamond disk diameter of optical grade with **minimum Ø180 mm**, well beyond **the state of the art, Ø140 mm**
- Disk thickness of **2.0 mm** for an appropriate structural stability and resonant thickness for wrong polarization (at the main frequencies of interest)
- Intensive collaboration along these years with industrial partner, Diamond Materials in Freiburg, Germany to meet disk target

Brewster-angle diamond window (DEMO)

- Extensive diamond growth experiments in microwave plasma reactors for both thermal and optical grade
- First of its kind free standing Ø180 mm **optical** CVD diamond disk with 1.3 mm average unpolished thickness
- For the first time, one side of Ø180 mm optical disk was successfully **polished** until all significant voids were removed (flatness < 6 µm)
- For the first time, very good **central tanδ** measured in a Ø180 mm, free standing, unbroken, **one side polished** optical disk: 1.3×10^{-5}
- For the first time, **Ø130 mm area tanδ mapping** performed over **one side polished** optical disk: very good values for D50 and D90

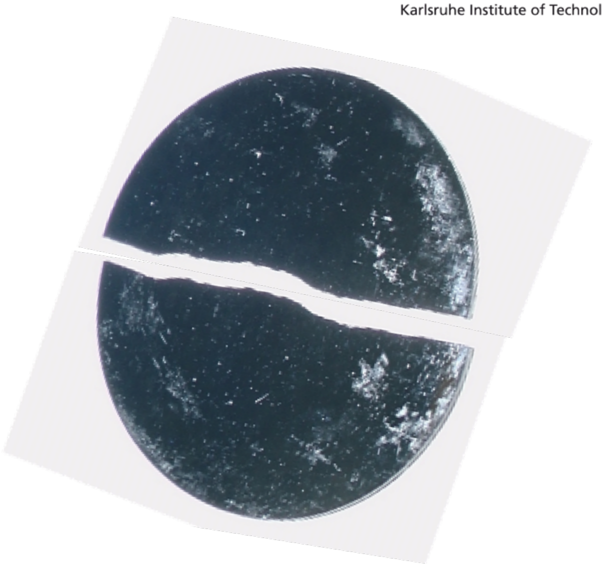
MPA CVD reactors

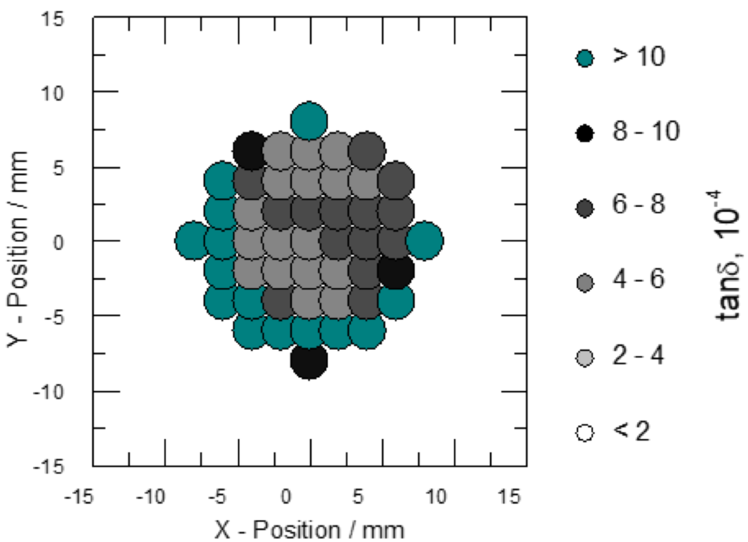


- Growth rate of 0.1-10 µm/h
- Nitrogen increases the growth rate but diamond quality shifts from optical grade to thermal grade (thermal application)
- The effect on the dielectric losses (tanδ) of defects like dislocations and **nitrogen-vacancy (NV) centers** introduced by the growing process has not fully investigated and understood so far

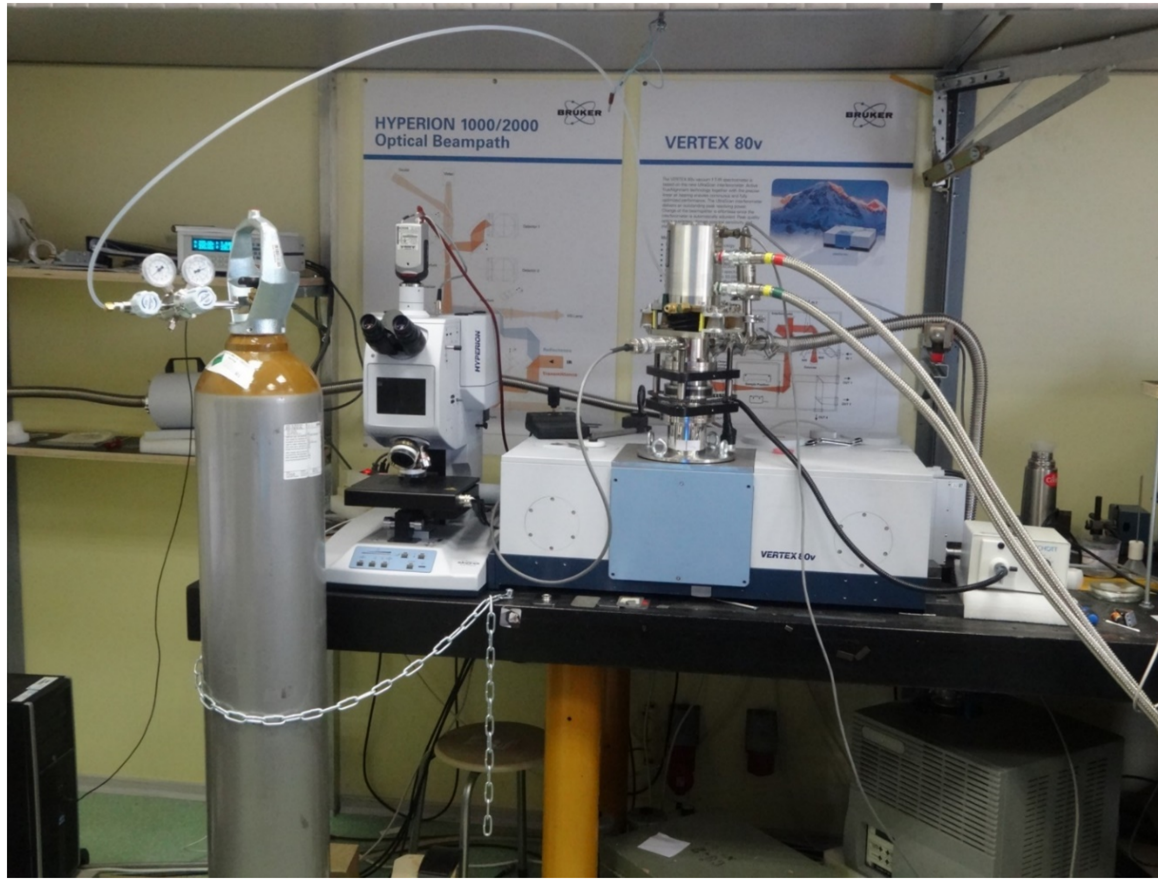
Neutron irradiated CVD diamond

- A 30 mm diameter and 1.11 mm thick CVD diamond disk was irradiated with a dose of 10^{24} n/m² (very high!)
- Before irradiation, tanδ = 8.7x10^{-6} @170 GHz
- After irradiation, the disk was broken into two parts due to handling operation
- After irradiation, a strong degradation of tanδ was observed
- Black colour after irradiation due to implementation of colour centres into the diamond lattice
- It is important to understand **the role of the n-irradiation damage** on the dielectric losses (tanδ) of diamond





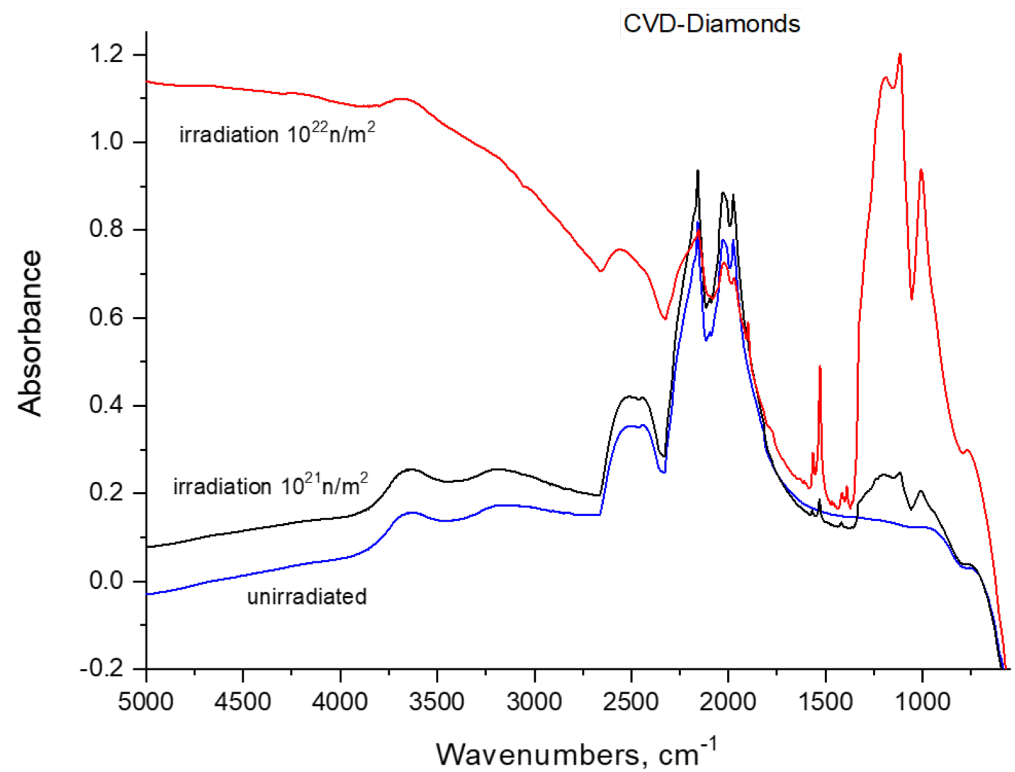
FTIR spectroscopy



General view of the FTIR spectrometer Vertex 80v with accessories at University of Latvia, Riga

FTIR spectroscopy: first results

- The unirradiated diamond sample shows a spectrum, which is common to synthetic diamonds
- Spectral lines characteristic for the diamond are observed in the region of 1900 - 2500 cm^{-1} (lines belong to the C-C vibrations)
- Going to the irradiated samples, significant changes appear, directly dependent on the radiation dose
- New bands appear, whose intensity increases with increasing dose
- Lattice disorder especially in the sample irradiated with 10^{22} n/m^2

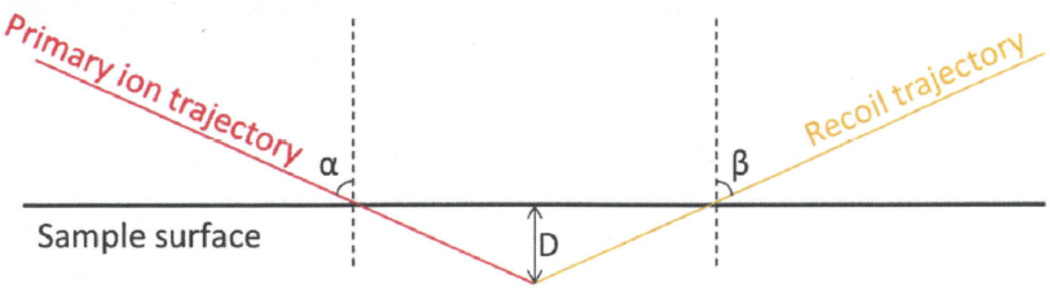


Small diamond samples

- 5 mm diameter
- Samples grown with different CH_4 / H_2 / N_2 – atmospheres during the CVD diamond growing process
- Target: determine the nitrogen content in the lattice of the samples
- If feasible, it might be possible to correlate the N content with the tanδ of the disks (for tanδ measurements the minimum required disk diameter is ~30 mm)

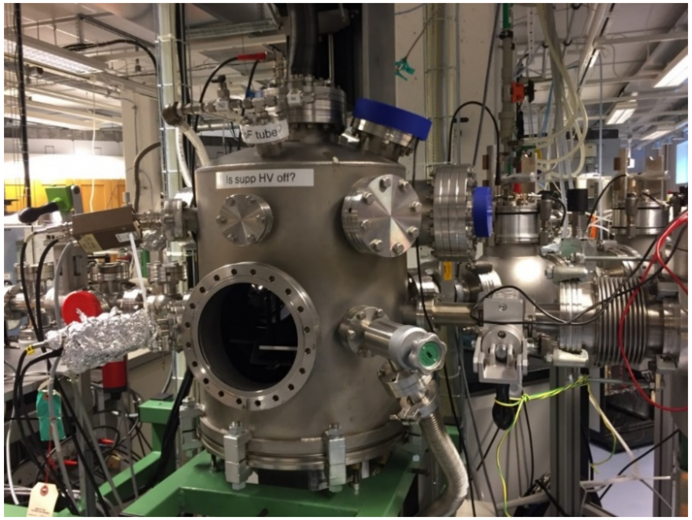
→ The N content was determined by **ToF-HIERDA technique** (Time of Flight – Heavy Ion Elastic Recoil Detection Analysis) at the Tandem Laboratory of Uppsala University

ToF-HIERDA technique - Uppsala



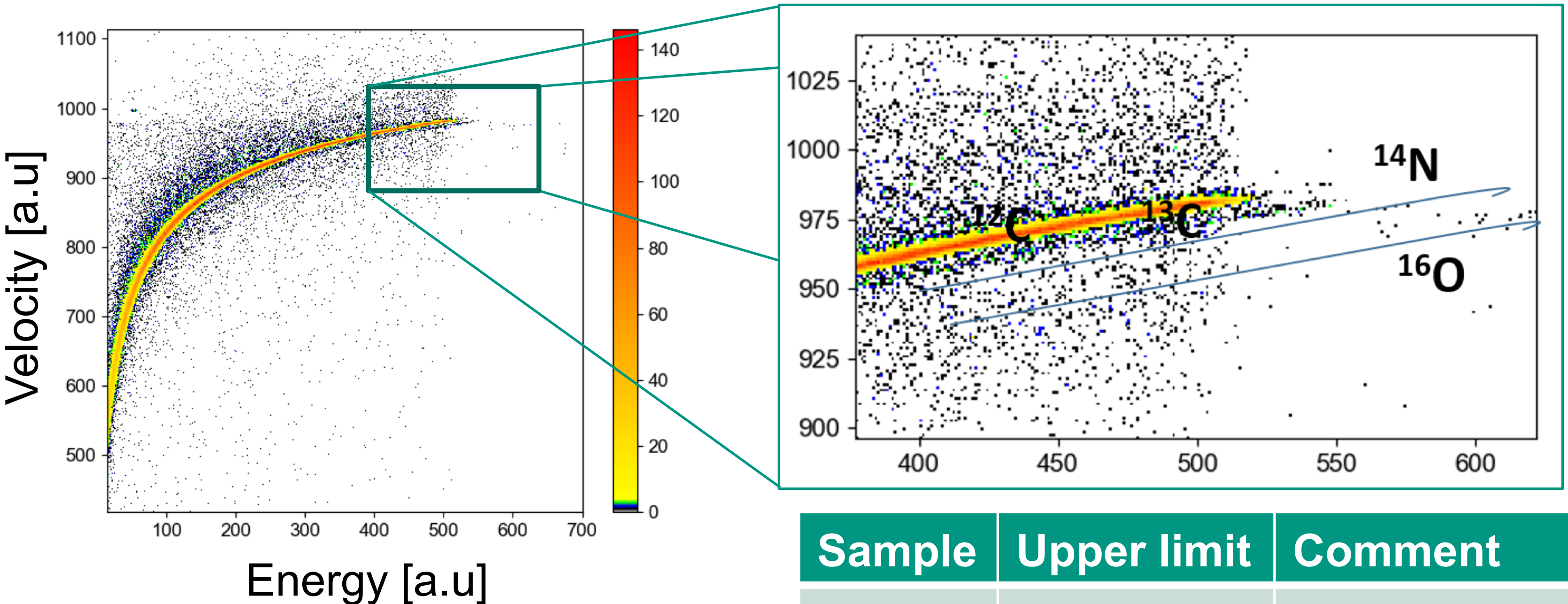
- Primary ions: 36 MeV ^{127}I
- ~ 30 minutes for data collection per sample
- Diamond samples and other samples for spectrum calibration

Holder for the samples



View of the setup in Uppsala

ToF-HIERDA spectrum of diamond samples



Sample	Upper limit	Comment
1	$1x10^{-2}$ %	
2	$0.8x10^{-2}$ %	Possible surface N
3	$1x10^{-2}$ %	
4	$2x10^{-2}$ %	Possible surface N
5	$1x10^{-2}$ %	
6	$3x10^{-2}$ %	

- N resulted quite low in concentration
- Fluorescence light for few seconds after starting irradiation

Conclusions and outlook

- First investigation have been started to study the effect on the dielectric losses in diamond of defects like dislocations and NV centers introduced by the CVD growing process and/or by subsequent neutrons and gammas irradiation
- FTIR spectroscopy
- ToF-HIERDA spectrometry

- RAMAN spectroscopy of non-irradiated and neutron irradiated diamond disk samples
- RAMAN spectroscopy of optical and thermal grade diamond disks

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the EURATOM research and training programme 2014-2018 and 2019-2020 under grant agreement No. 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.