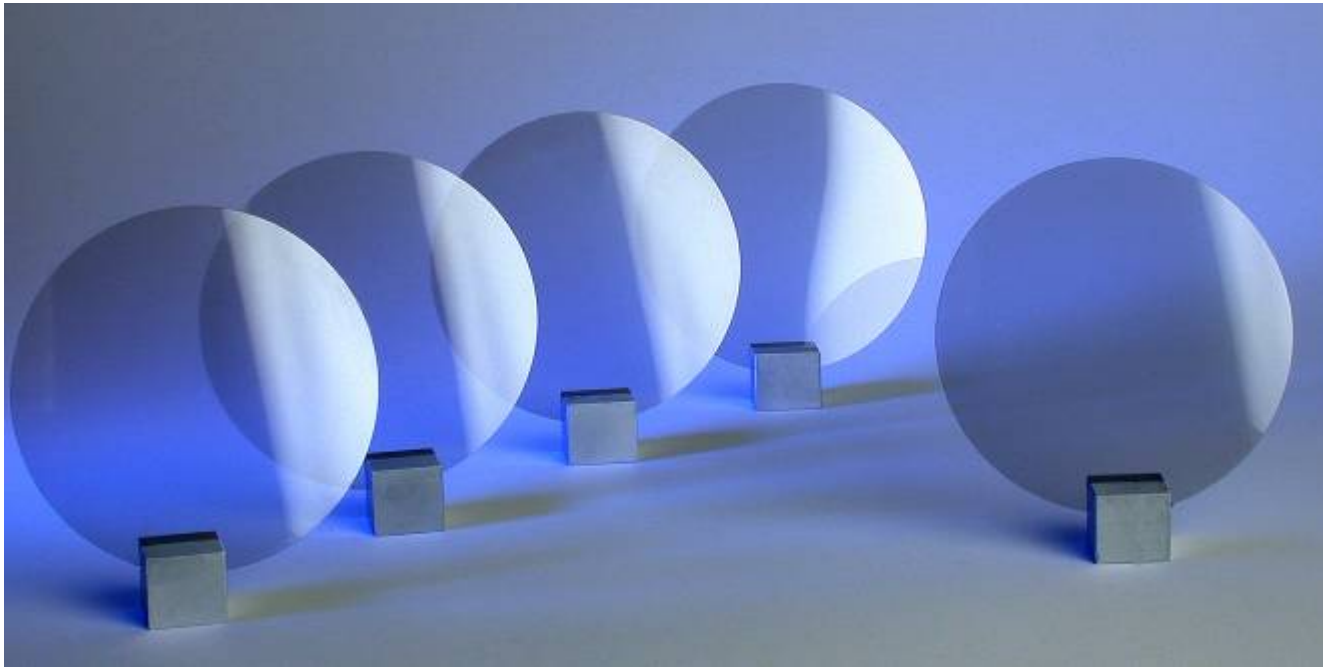


Diamond Materials – a Fraunhofer Spin-Off Company

Eckhard Wörner

Tullastraße 72, 79108 Freiburg, Germany
woerner@diamond-materials.de



**Diamond
Materials**

Advanced Diamond Technology

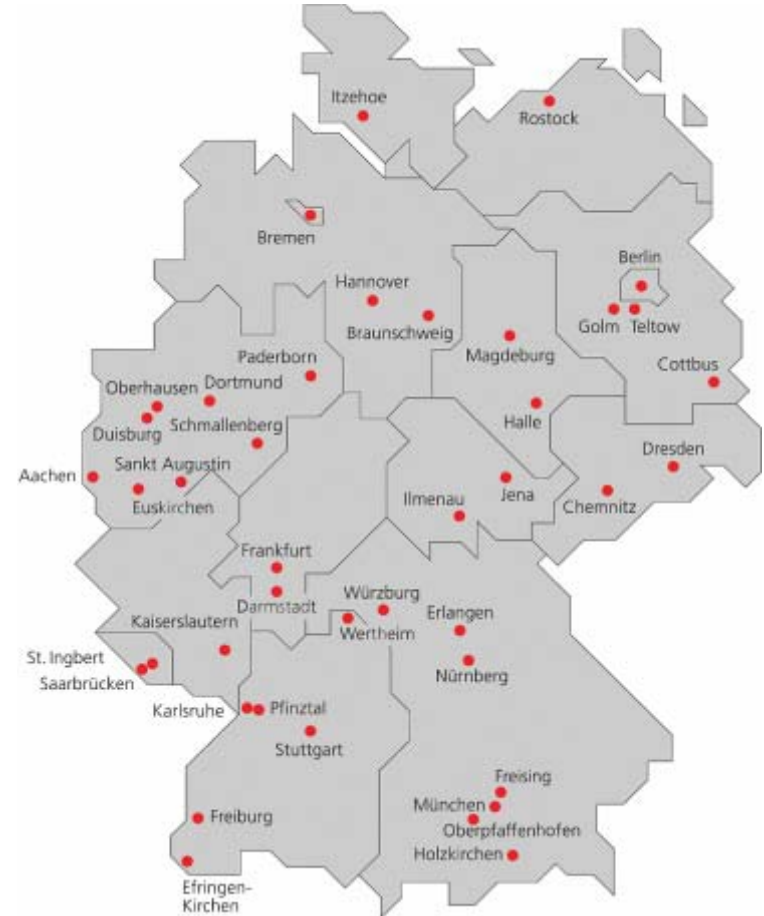
Outline

- **Some facts about “Diamond Materials” and Fraunhofer Society**
- **Deposition and processing**
- **Applications**
- **Research activities**

The Fraunhofer Society

Largest organization for *applied* research in Europe

- founded in 1949
- 58 Institutes in more than 40 locations
- 12 500 employees
- 1 billion € research budget



**Diamond
Materials**

Advanced Diamond Technology

Fraunhofer Institute for Applied Solid State Physics (IAF)

Location: Freiburg, Germany
Founded: 1957
Staff: 200 total
Funding: 20 million € / year
(BMVg, BMBF, Industry)
Area: 8.000 m² laboratories and offices
800 m² clean room
Spin-offs: EpiNova GmbH
m2k-Laser GmbH
Diamond Materials GmbH



EPINOVA
III-V EPITAXIAL SOLUTIONS


Fraunhofer Institut
Angewandte
Festkörperphysik

m2k *Laser*
High-Brightness Diode-Lasers

**Diamond
Materials**

Advanced Diamond Technology

Some facts about „*Diamond Materials*“

- **Founded 2004**
as a “Spin off” of the Fraunhofer IAF
- **Staff: 8**
mostly physicists, engineers
- **Specialized on**
growth and processing of high quality CVD diamond
- **Equipment**
Deposition reactors
Processing machines (grinding, polishing, laser cutting,...)
characterization tools
- **Know How**
experience in diamond for about 20 years
scientific background (publications, talks,...)
diamond deposition, processing, product development

Outline

- Some facts about “Diamond Materials”
- **Deposition and processing**
- Applications
- Research activities

Some facts about *Diamond*



optical

broad spectral transparency

thermal

highest thermal conductivity

mechanical

hardest material

90 t/year for industrial applications
($\frac{3}{4}$ HPHT-diamonds)

electrical

wide bandgap

highest charge carrier mobility

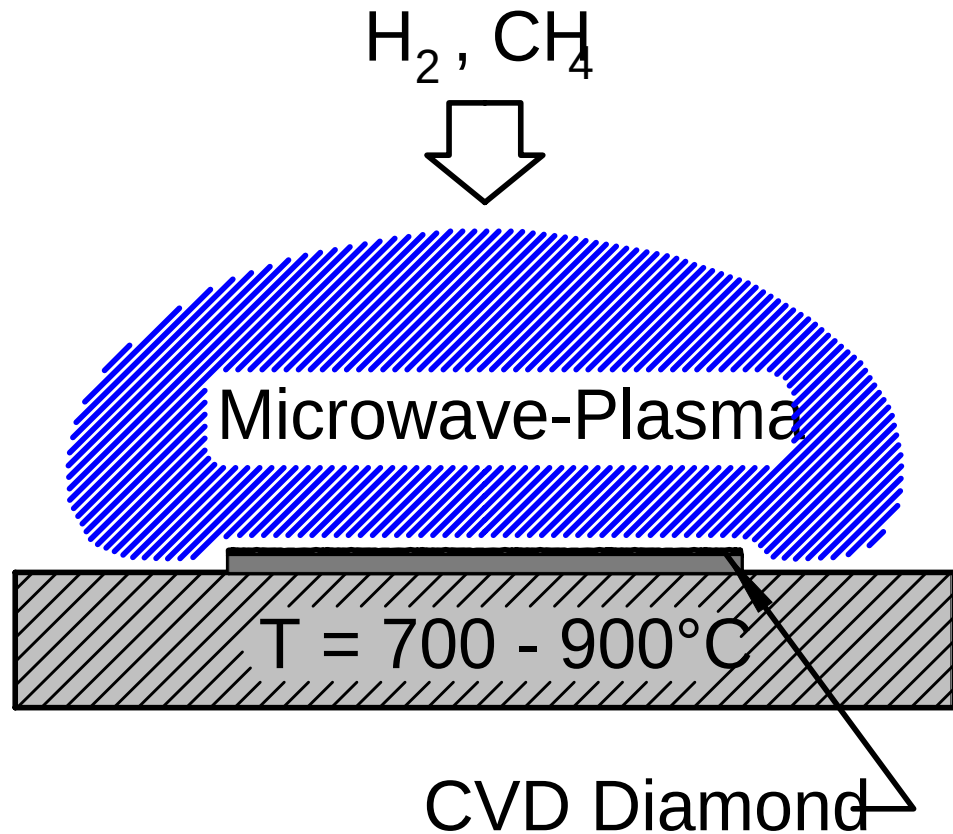
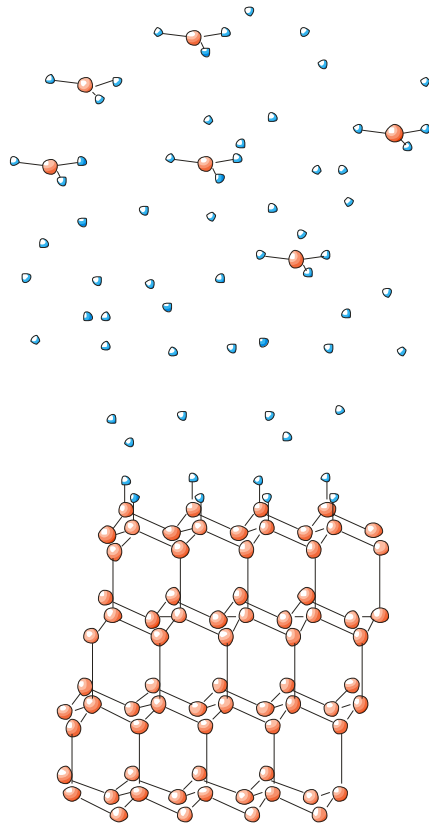
negative electron affinity on {111}-
planes (0,7 eV)

**Diamond
Materials**

Advanced Diamond Technology

Low pressure deposition of diamond:

CVD: Chemical Vapor Deposition

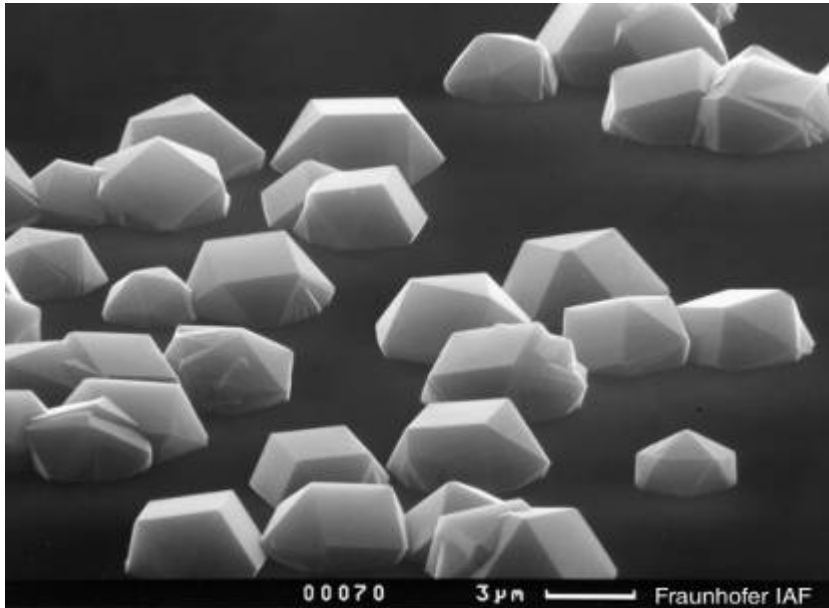


**Diamond
Materials**

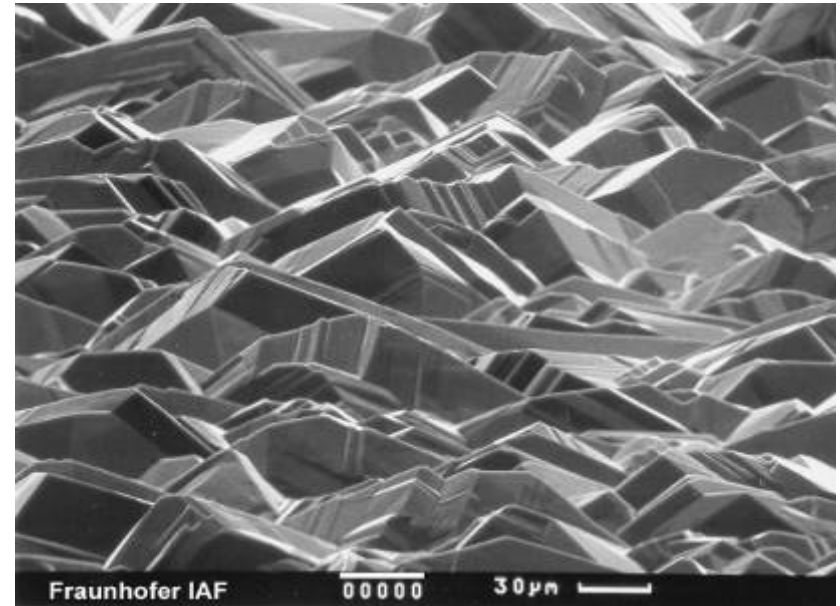
Advanced Diamond Technology

Synthesis

Isolated crystallites (nucleation)

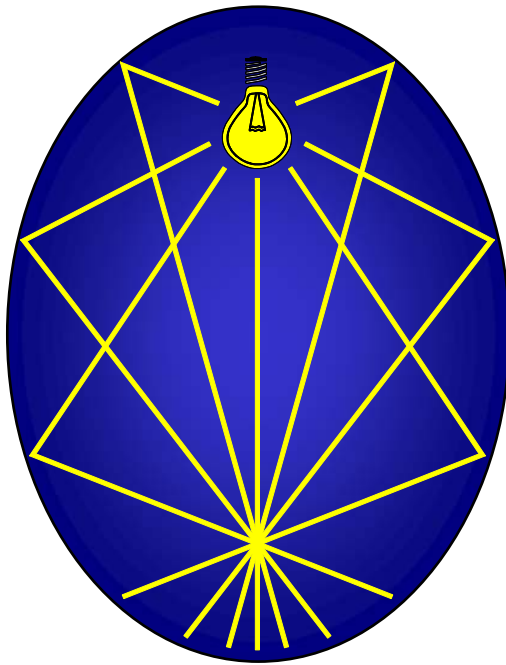


polycrystalline plate

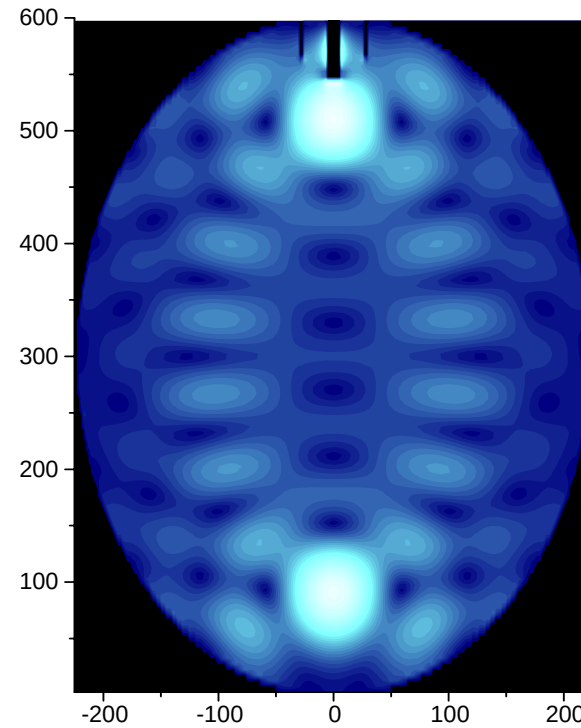


Idea of a new reactor

light



microwave



Proprietary deposition technology: P6



**Diamond
Materials**

Advanced Diamond Technology

P30 Reaktor

P30



Fraunhofer
Institut
Angewandte
Festkörperphysik

**Diamond
Materials**
Advanced Diamond Technology

915 MHz, 30 kW

Properties of our reactors

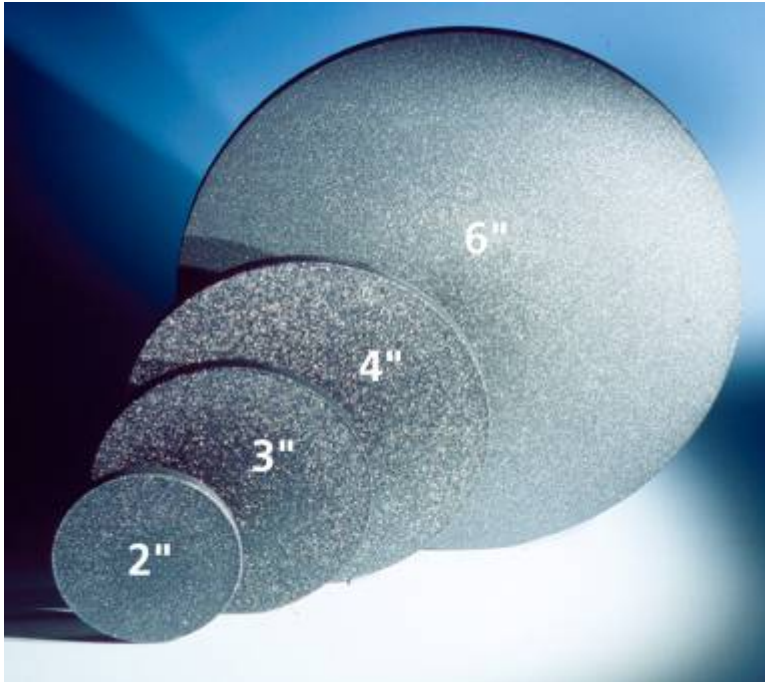
- **Large area**
homogeneous deposition of CVD-diamond on
3" and 6" substrates
- **High-quality diamond**
Properties of CVD diamond disks identical to those
of perfect single diamond crystals
- **Stability**
Long-term operation possible, no plasma instabilities
- **Versatility**
Reactor can be run under various
conditions (pressure, power etc.)



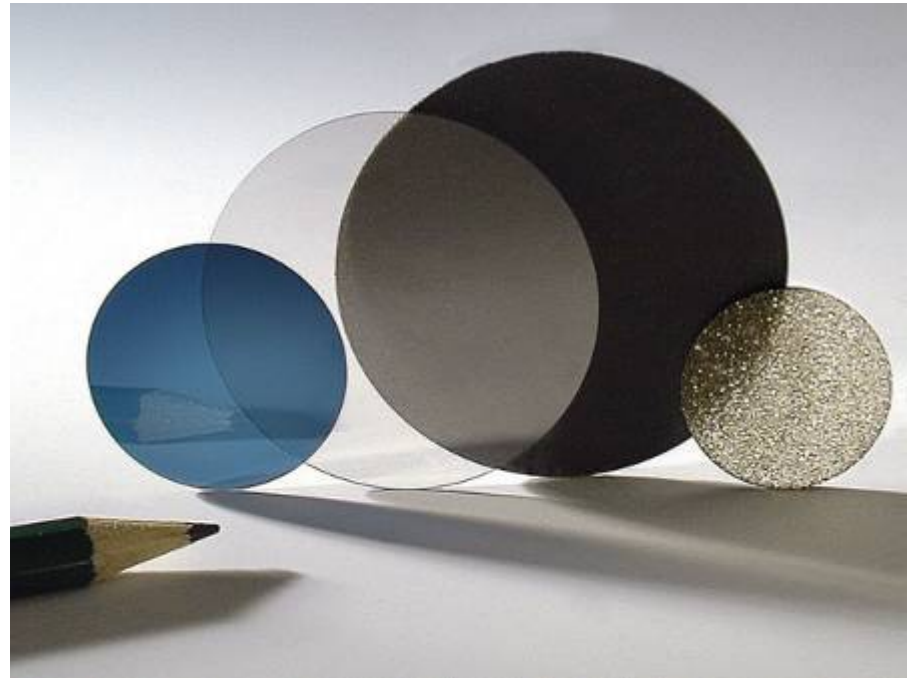
**Diamond
Materials**

Advanced Diamond Technology

CVD diamond wafers



**Deposition area: 2 - 3" Ø (2.45 GHz)
4 - 6" Ø (915 MHz)**

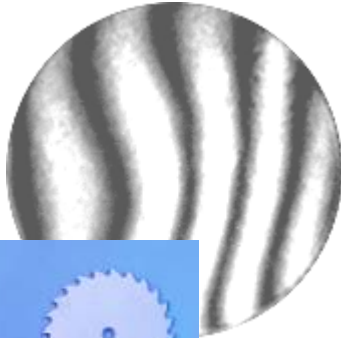


Tailoring of material properties

**Diamond
Materials**

Advanced Diamond Technology

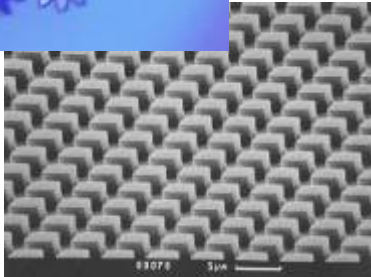
Processing techniques



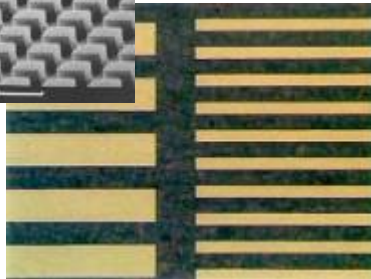
Grinding and polishing



Laser cutting



Plasma etching



Metallization



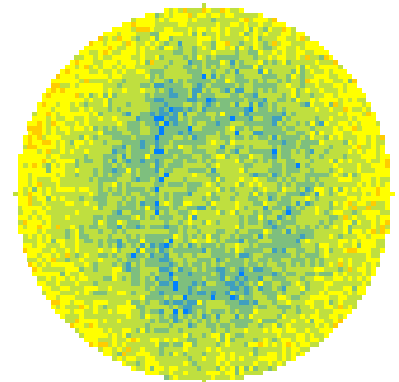
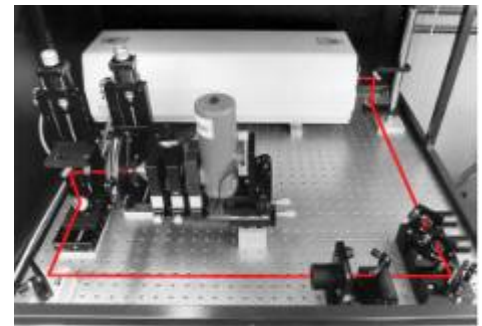
Mounting techniques

**Diamond
Materials**

Advanced Diamond Technology

Characterization and quality control

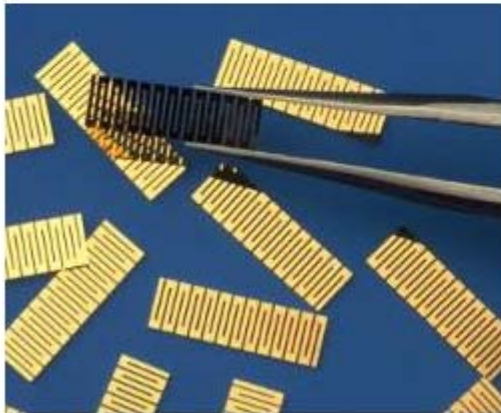
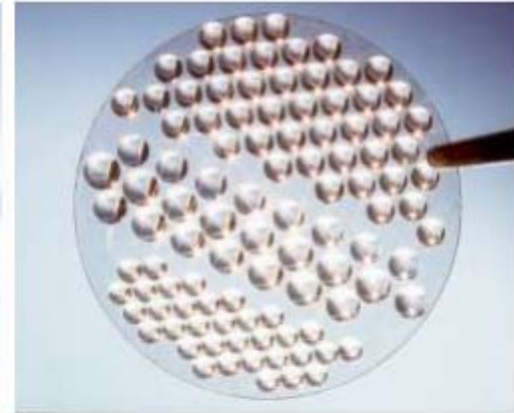
- **Spectroscopy**
 - FTIR / UV-VIS / Raman / PL
- **Material properties**
 - Thermal conductivity (vs. temperature and position)
 - mechanical properties (Young's Modulus, tensile strength)
- **Geometrical Specifications**
 - thickness homogeneity, planarity, roughness
 - wavefront distortion
- **QM system**
 - data locking of all deposition runs / characterization results - each product can be assigned to a deposition run
 - Quality documents



Outline

- Some facts about “Diamond Materials”
- Deposition and processing
- **Applications**
- Research activities

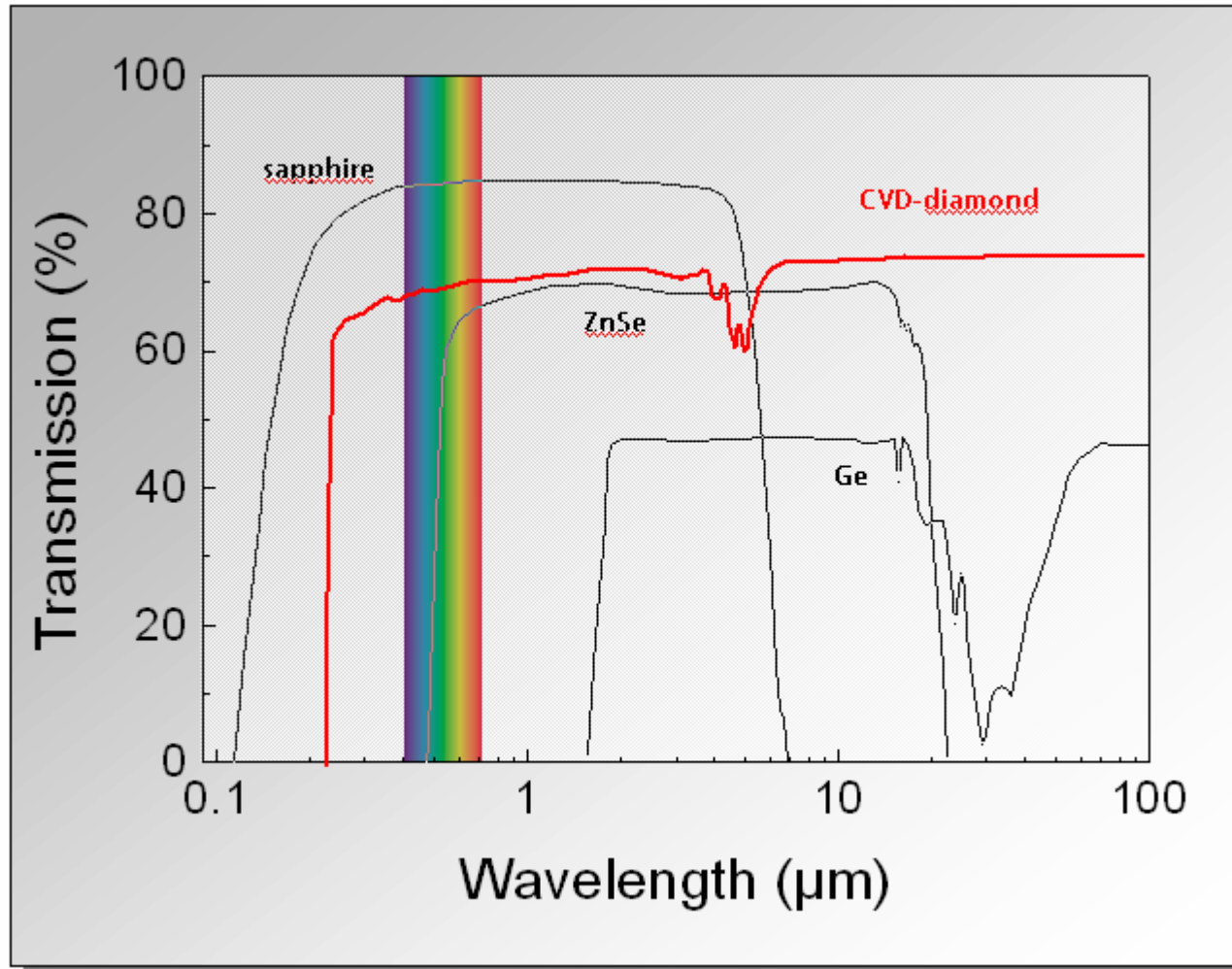
Applications



**Diamond
Materials**

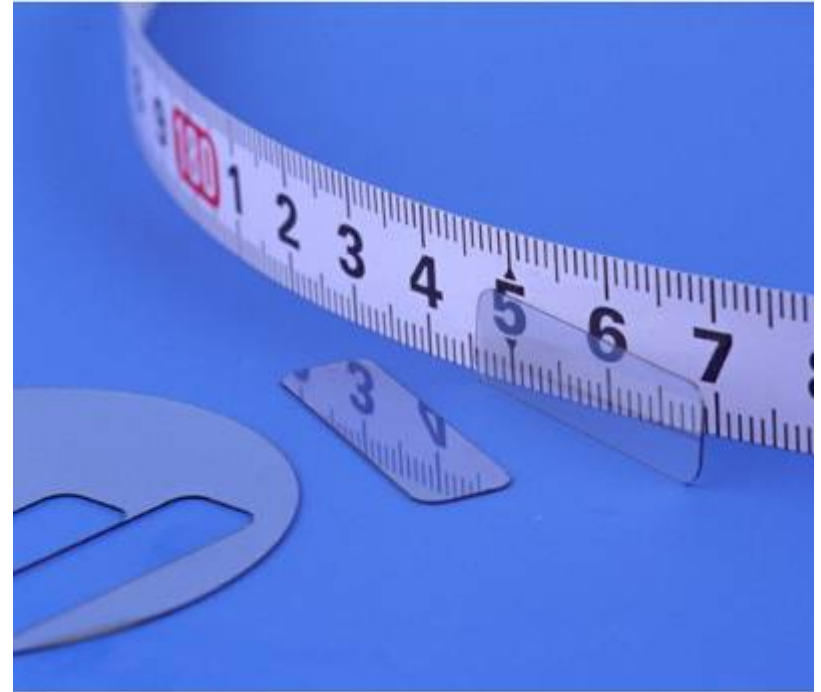
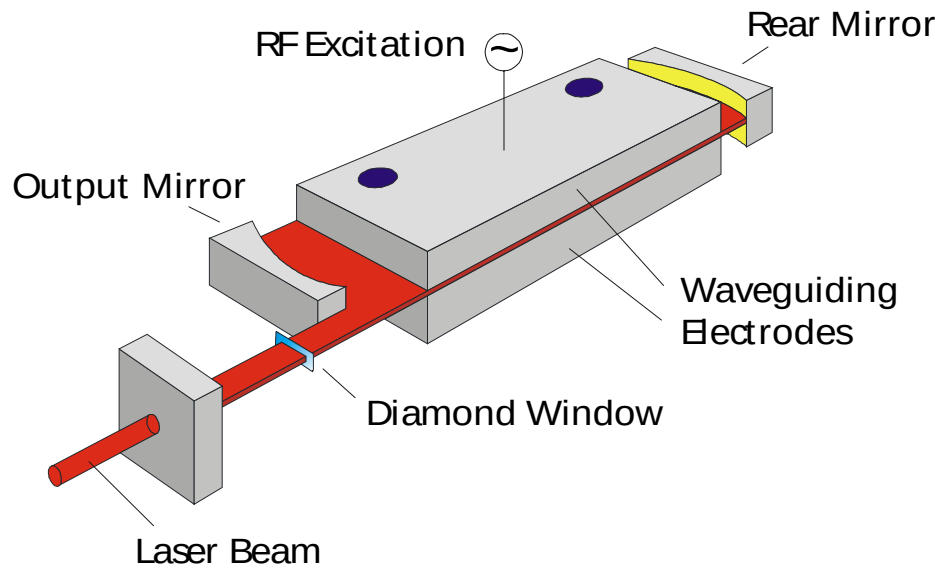
Advanced Diamond Technology

Optical properties of diamond: Transmisson



Laser windows

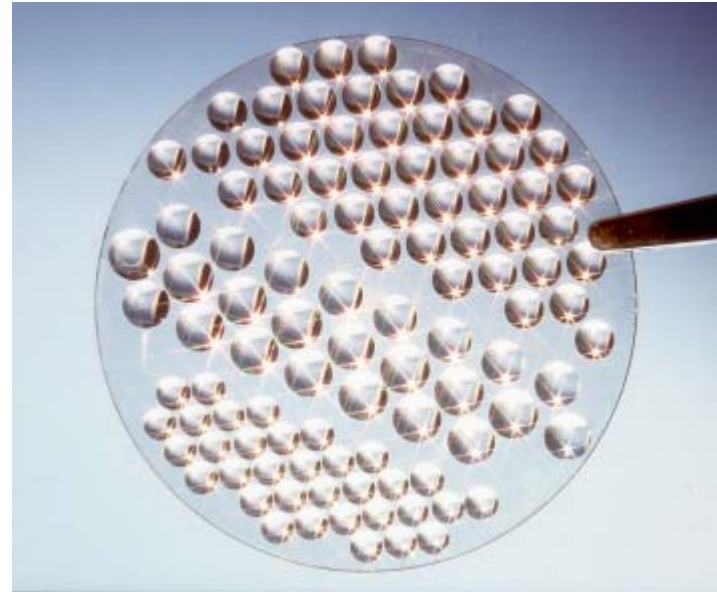
CO₂ Slab Laser



**Diamond
Materials**

Advanced Diamond Technology

CVD diamond focussing lenses



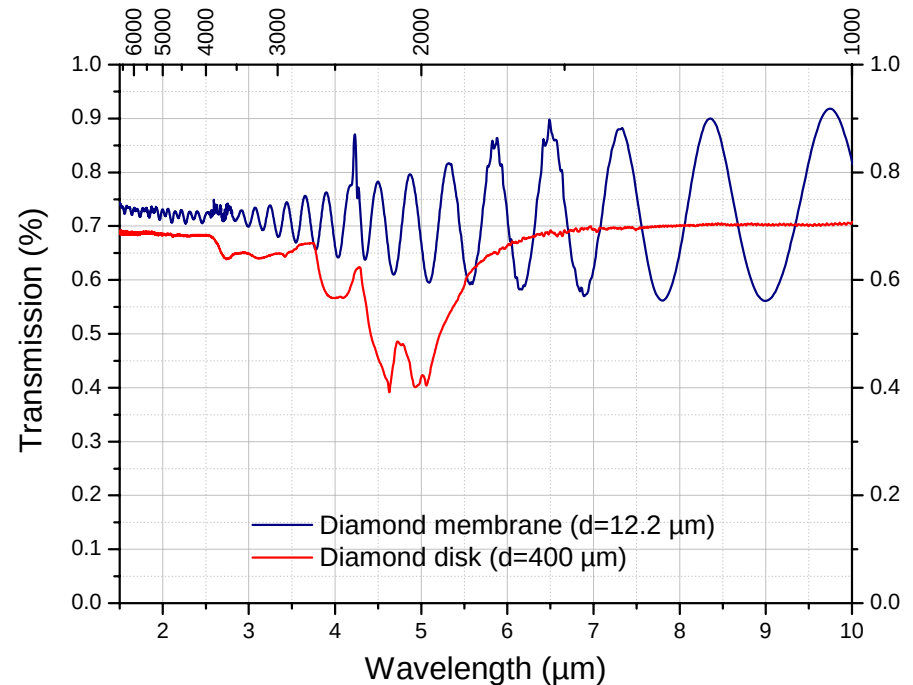
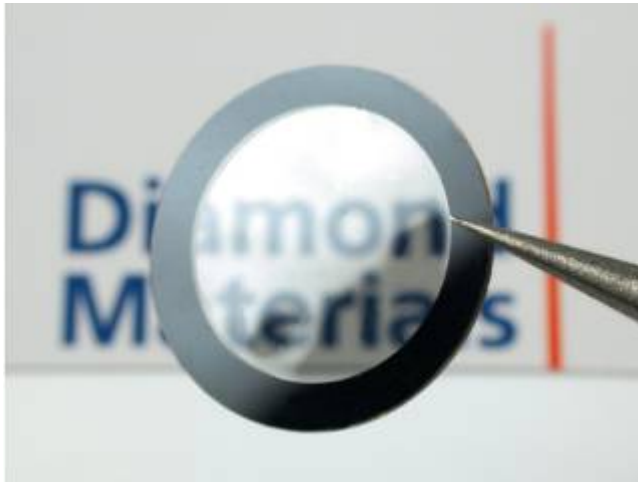
Applications:

- focussing optics for CO₂-laser surgery

Membranes



Thickness: 5-100 μm , $\varnothing$ up to 75mm

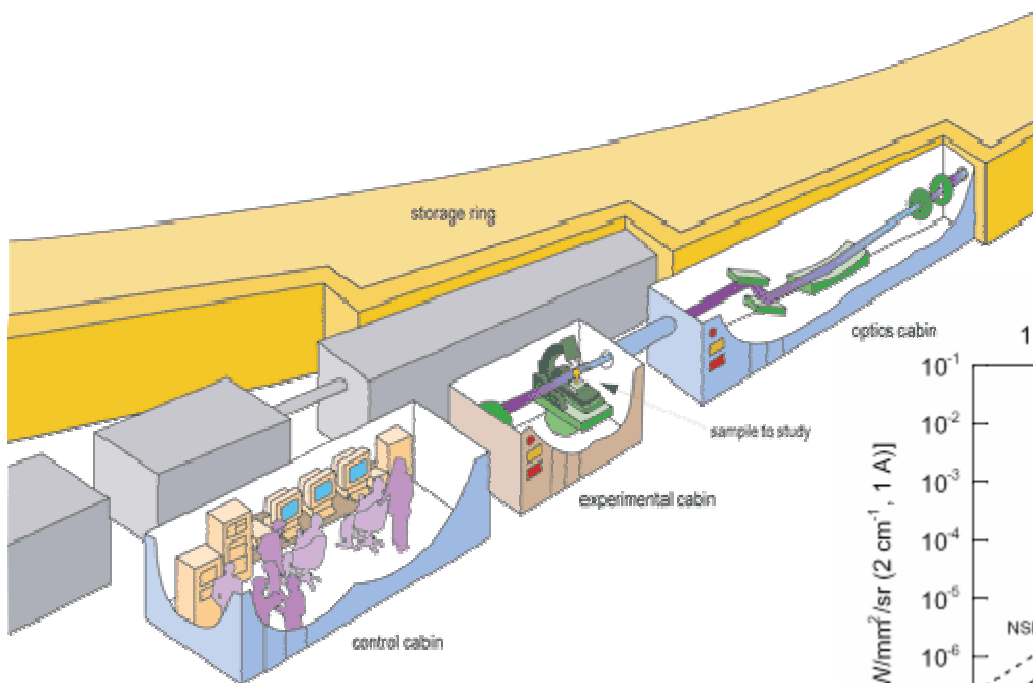


- Detectors for alpha particles and ions
- Fluorescence monitors
for γ rays and electron beams
-

**Diamond
Materials**

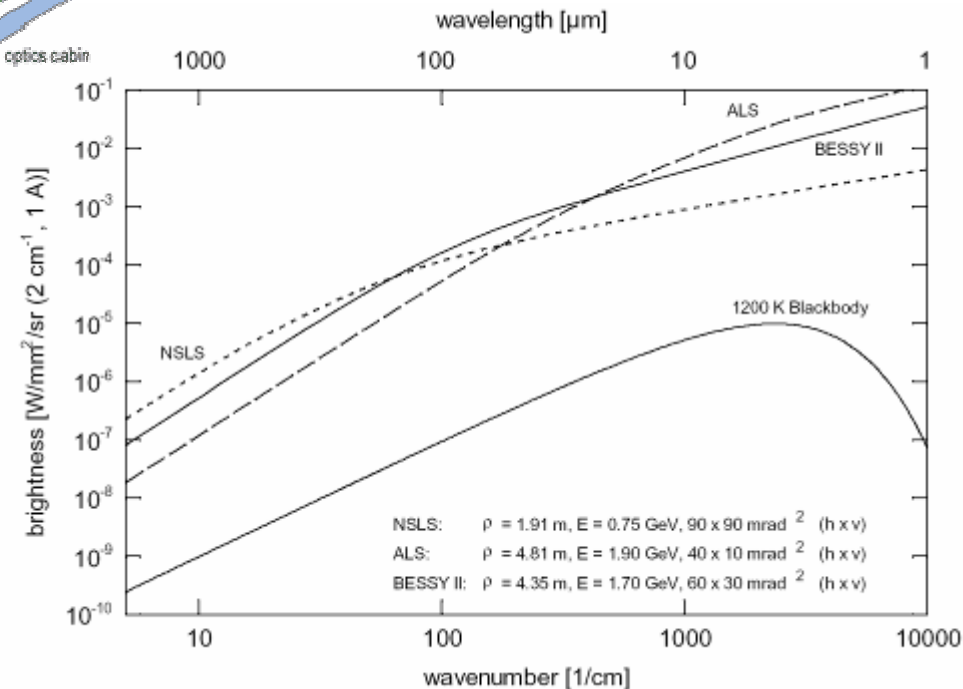
Advanced Diamond Technology

Diamond windows for synchrotron radiation



Synchrotron-radiation

- broad band
- collimated
- extreme intensities



**Diamond
Materials**

Advanced Diamond Technology

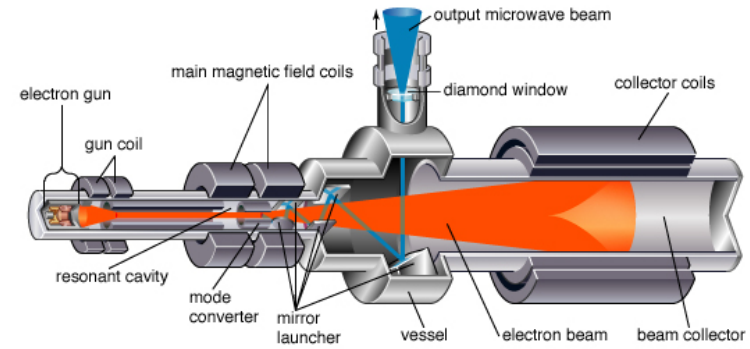
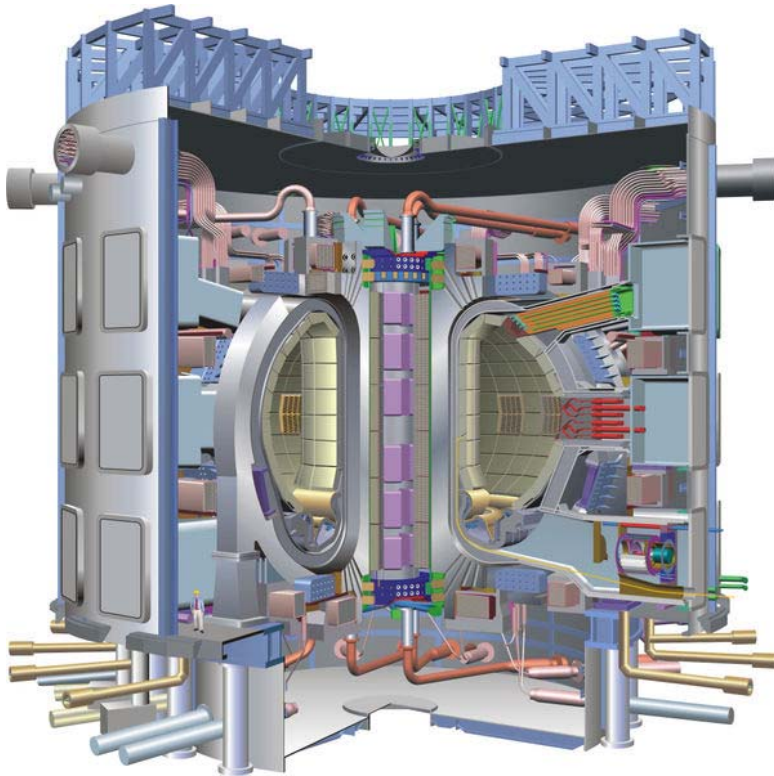
CVD diamond UHV-windows



IR-windows

- 1° wedge
- 250°C bakable
- UHV-tight ($< 1 \times 10^{-10}$ mbar l/sec)
- plane (< 1 fringe/cm @ 633 nm)

Gyrotron windows



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Gyrotron tube



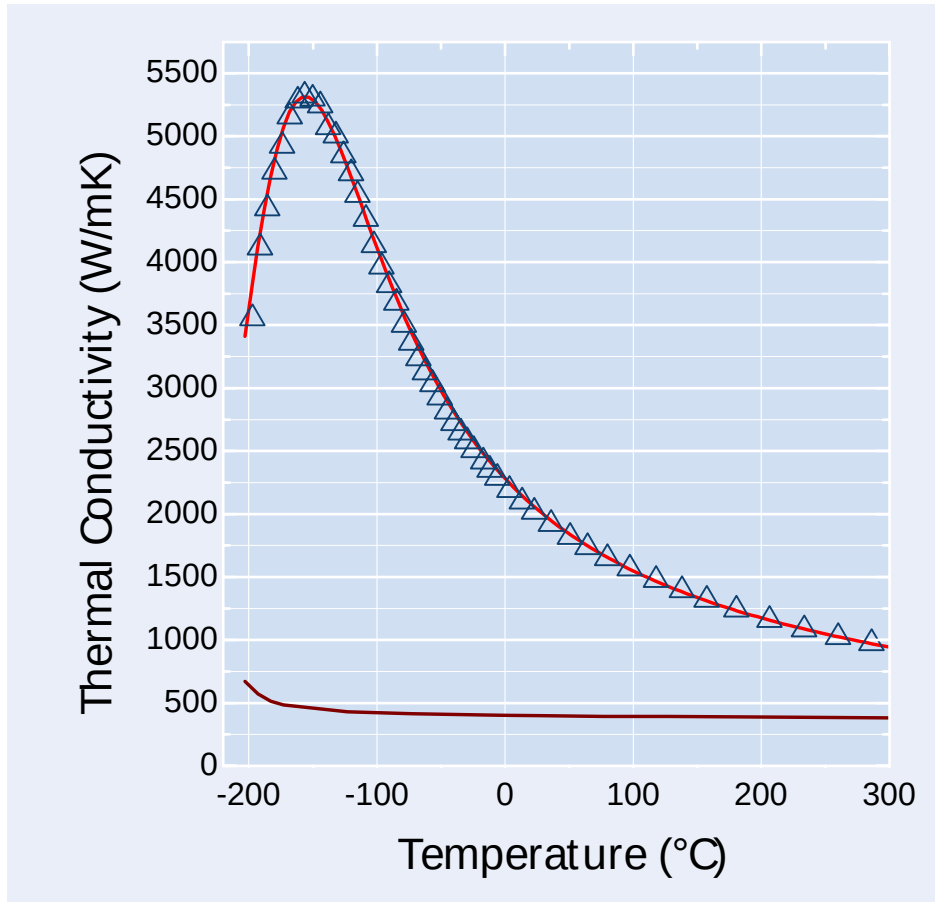
Gyrotron window (IAF)

ITE
R

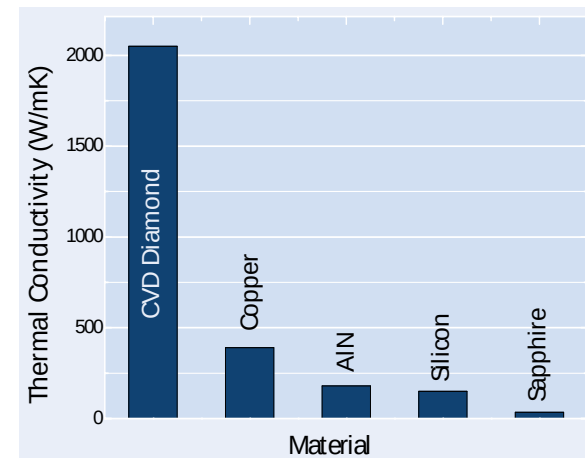
**Diamond
Materials**

Advanced Diamond Technology

Thermal conductivity of CVD diamond



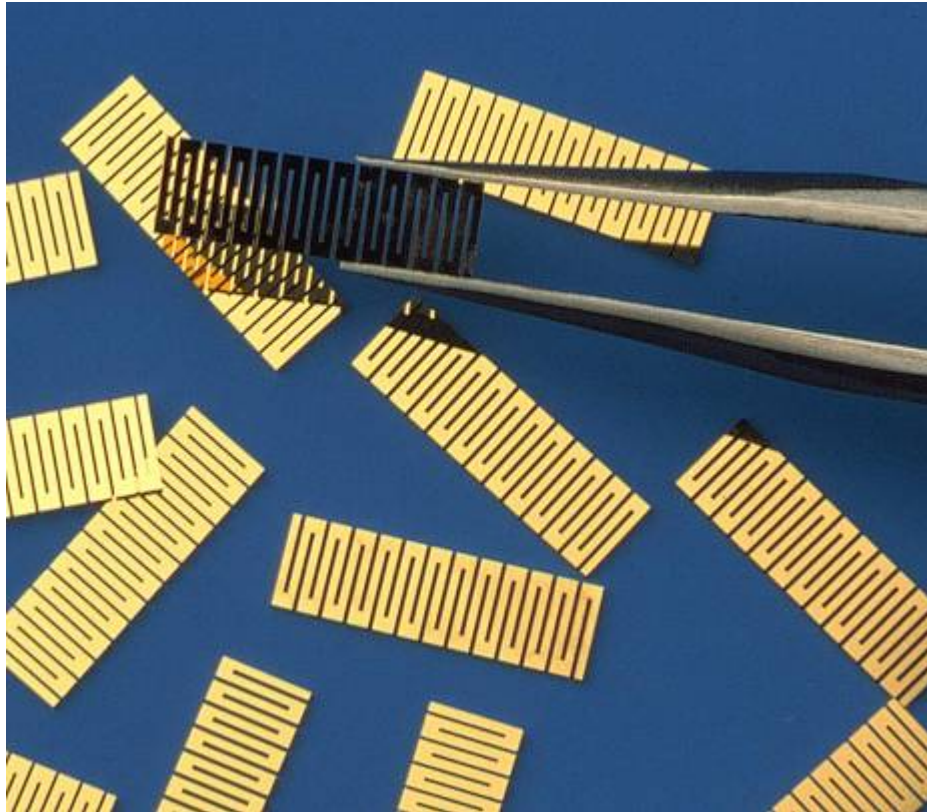
Thermal conductivity
2000 W/mK at RT
5400 W/mK at -150°C



**Diamond
Materials**

Advanced Diamond Technology

Thermal management applications: Heat spreaders

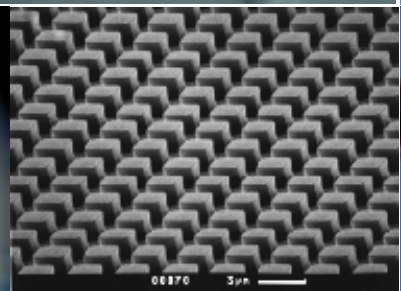
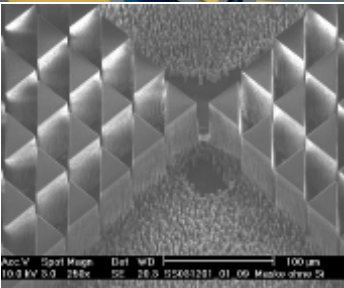
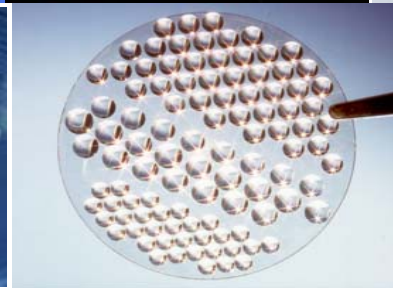
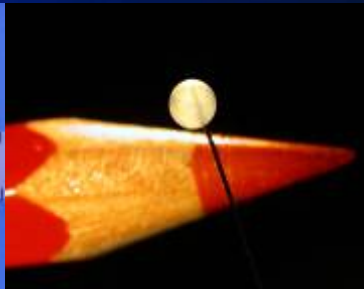


Metallization

- adhesion layer
- diffusion barrier
- wetability layer

Flexibility

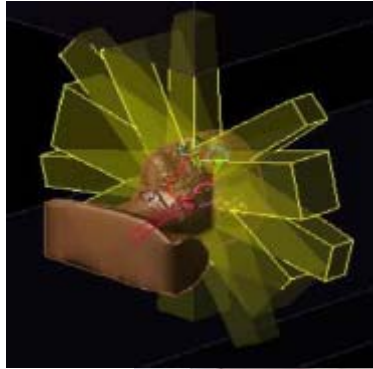
- due to stress relieving trenches



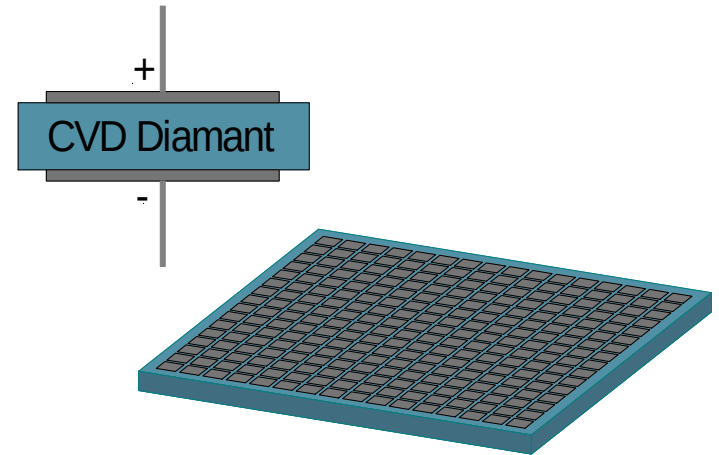
Outline

- **Some facts about “Diamond Materials”**
- **Deposition and processing**
- **Applications**
- **Research activities (in cooperation with Fraunhofer IAF)**

CVD diamond for dosimetric applications



IMRT device



Advantages of diamond:

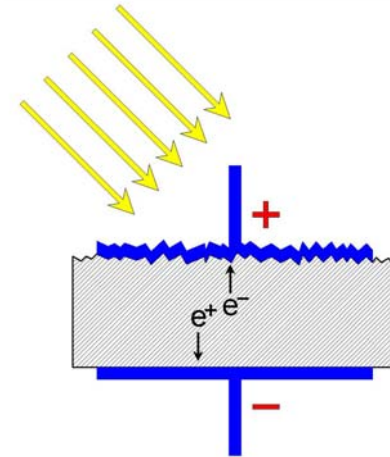
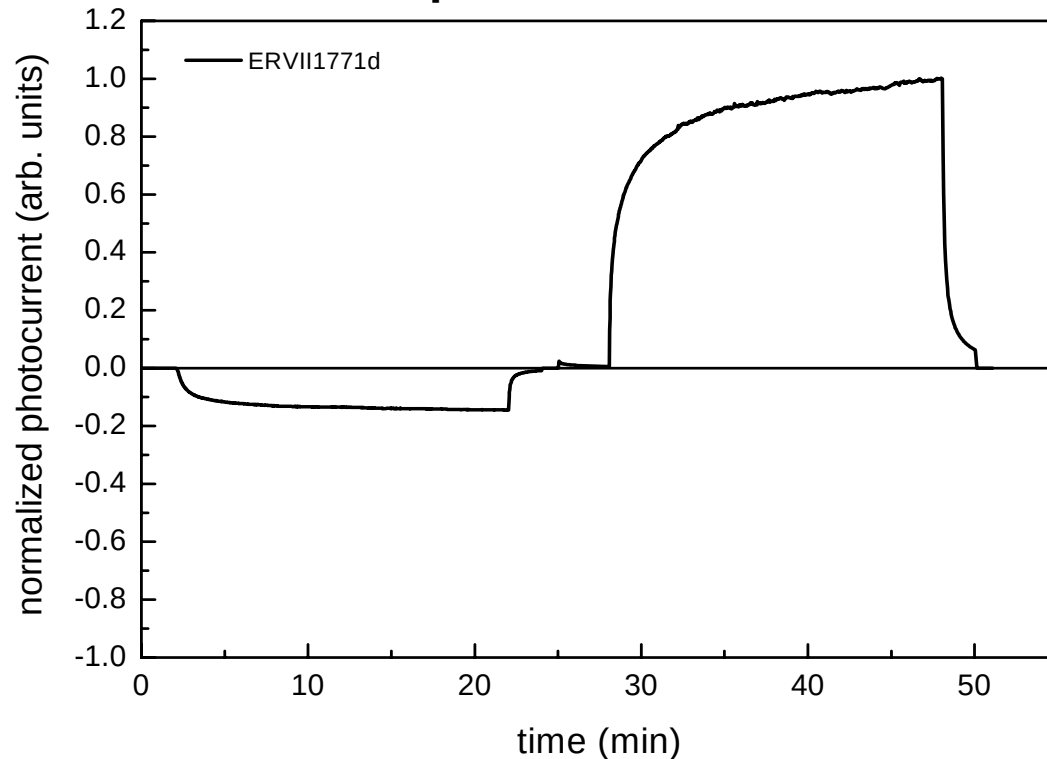
- tissue equivalence
- radiation hardness

**Diamond
Materials**

Advanced Diamond Technology

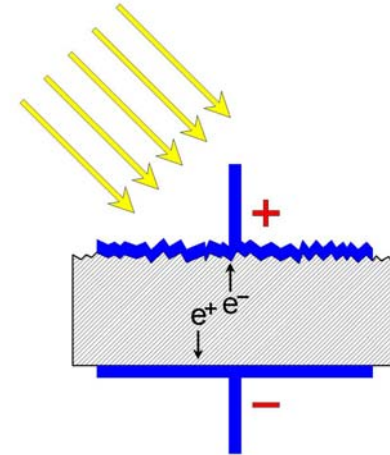
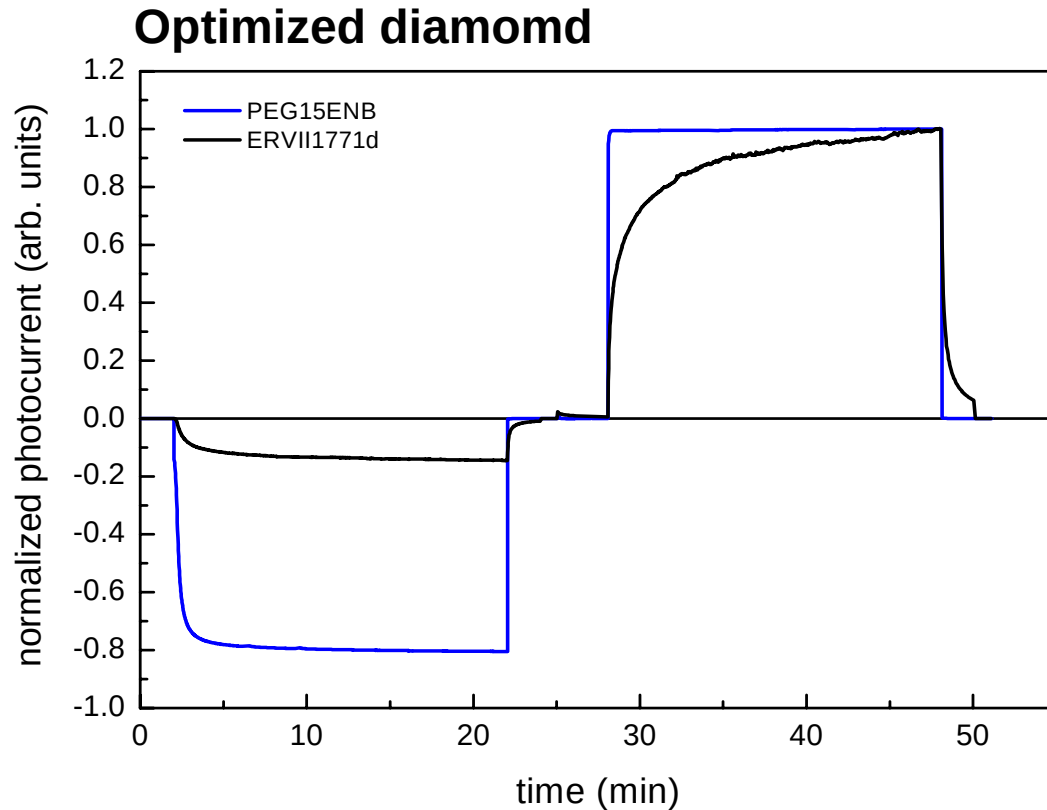
CVD diamond for dosimetric applications

Results for optical diamond



Slow rise and decay
⇒ **Due to filling of traps**

CVD diamond for dosimetric applications



Slow rise and decay
⇒ **Due to filling of traps**

EU-Project „DIAMOND“

DIAMOND

Development of Innovative, Accurate, Monolithic, CVD Diamond Array Based Radiation Dosimeter System

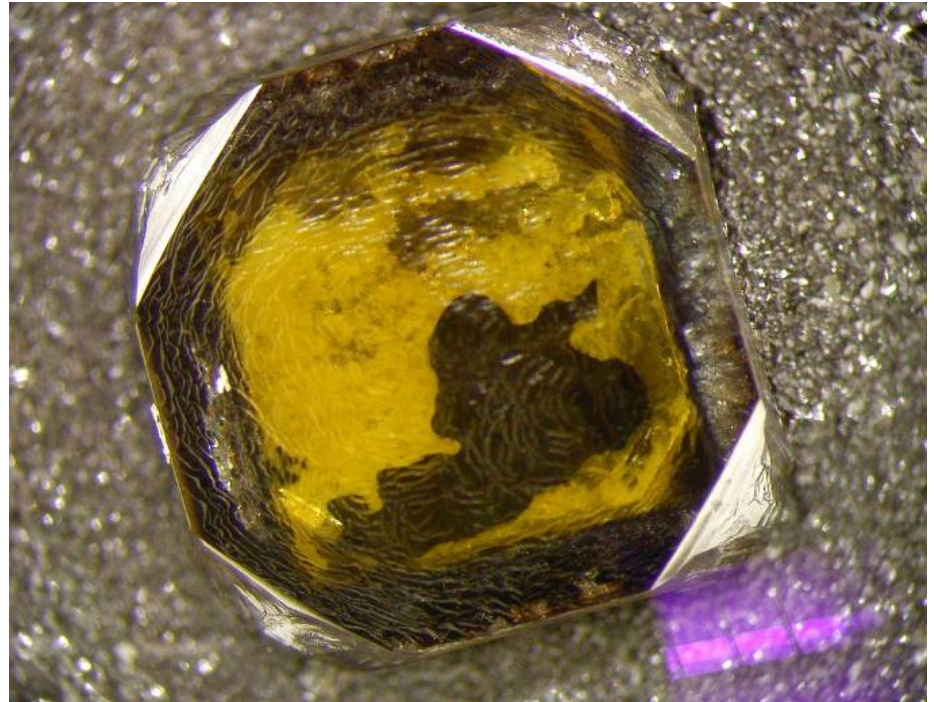
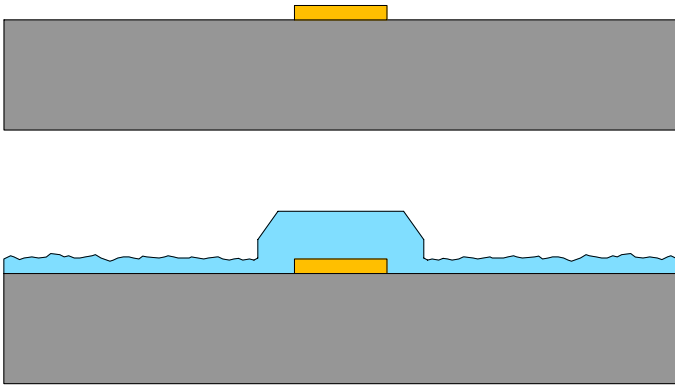


Diamond single detectors

**Diamond
Materials**

Advanced Diamond Technology

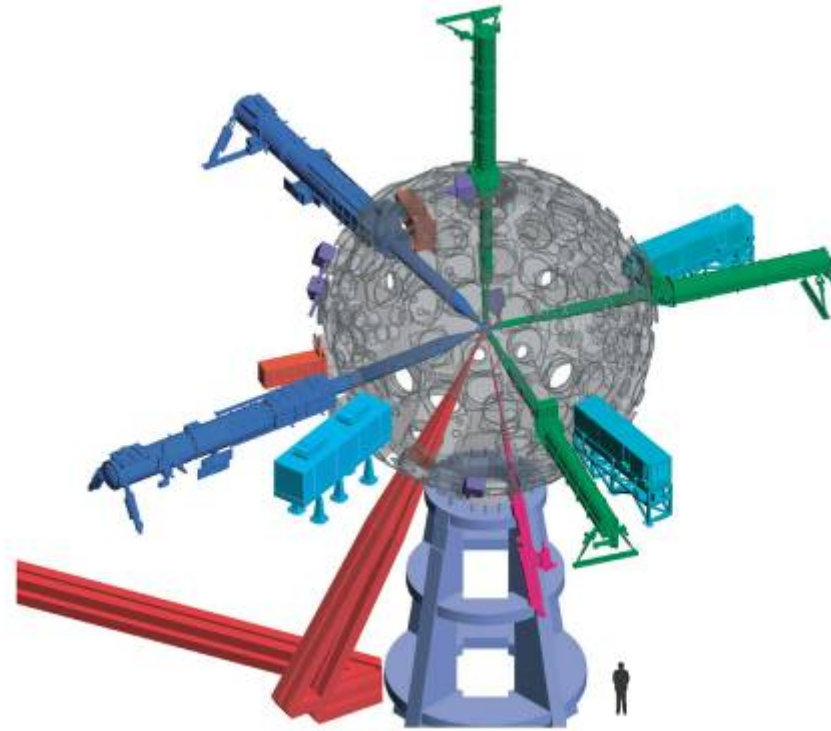
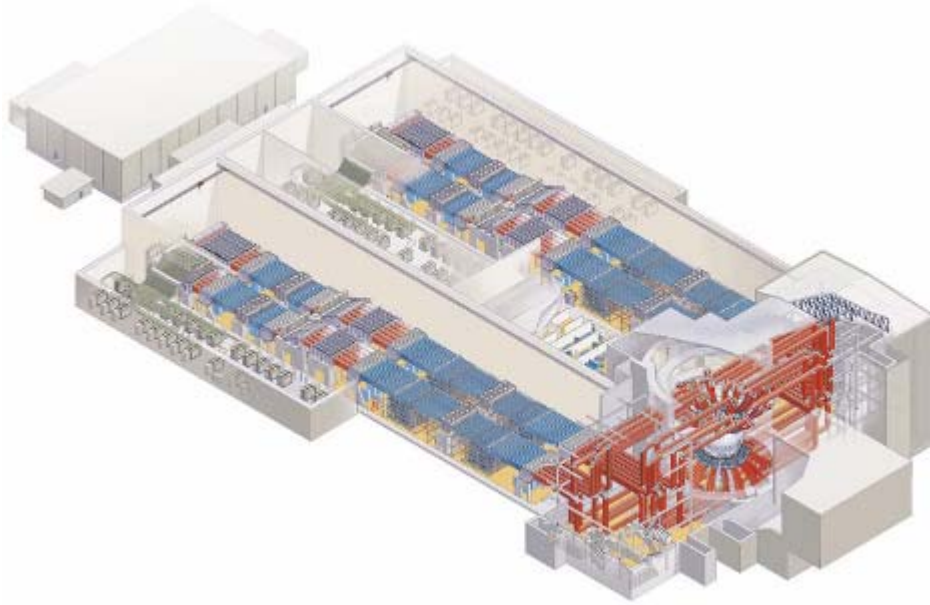
Growth of single crystals



CVD diamond single crystal
5x5mm, 500µm thick



Inertial confinement fusion



Largest laser system (finished 2010)

- Nd:glas Laser: 192 lasers, cross section 40cm
- power : 500 trillion Watt (1000 x total power of the US)
- Pulse energy: 1.8 Mega joule
- Pulse duration 3-4 ns

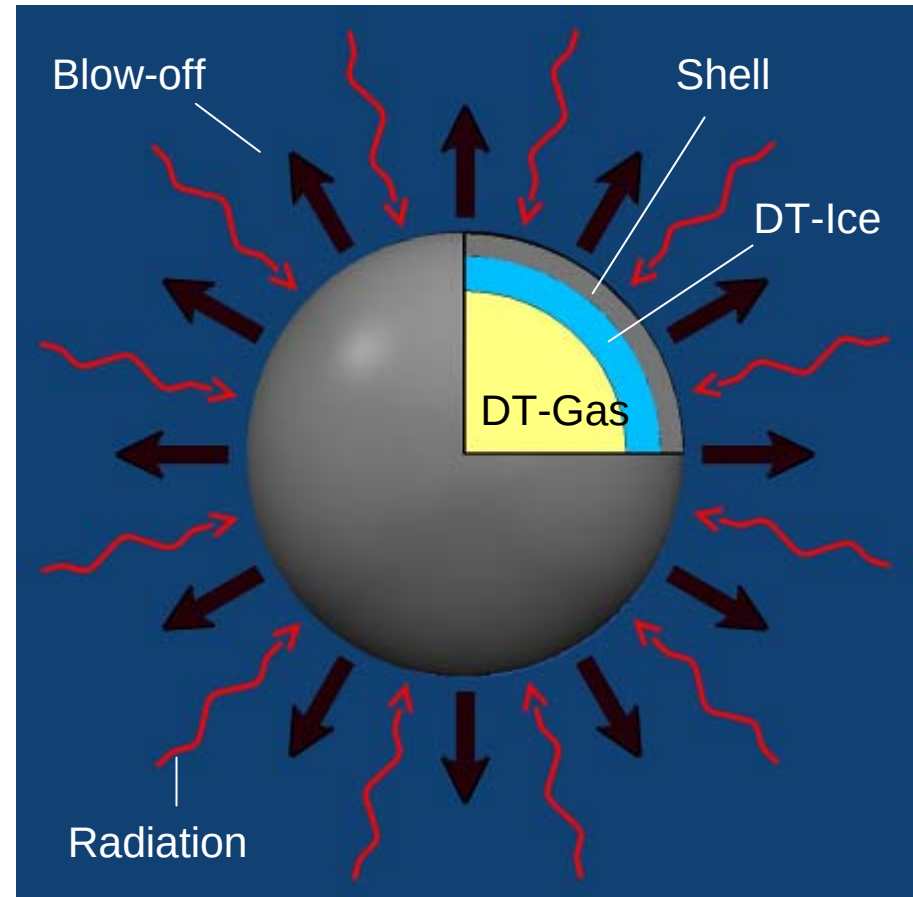
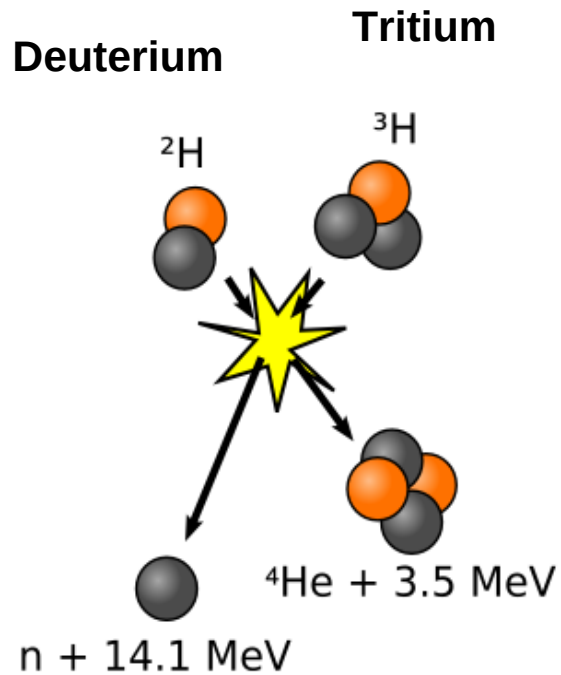


Fraunhofer



Institut
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Festkörperphysik

Inertial confinement fusion

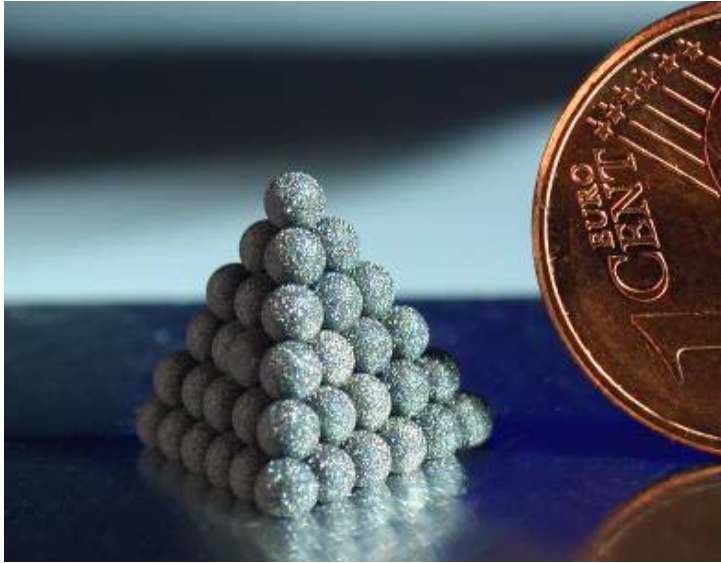


Fraunhofer



Institut
Angewandte
Festkörperphysik

Diamond mandrels for NIF



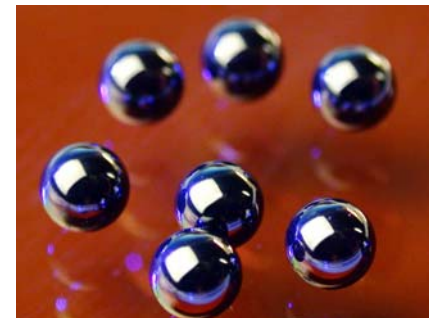
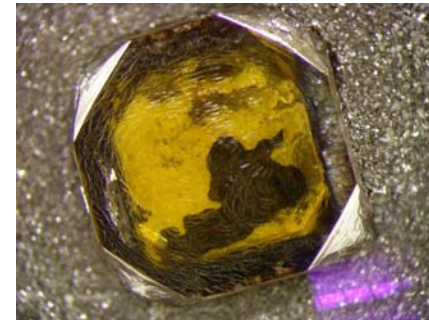
Properties:

- 5 nm surface roughness
- < 25 nm sphericity
- < 10 μm hole diameter



Conclusion

- **Optical, thermal and mechanical diamond products are on the market**
- **Detector applications:
dosimetry / array / particle detectors /
single crystals**
- **Research:
biochemistry / electronics / MEMS / ...**



cvd-diamond.com

**Diamond
Materials**

Advanced Diamond Technology