Thermal applications of low-pressure diamond

R. Haubner and B. Lux

Institute of Chemical Technology of Inorganic Materials
Technical University of Vienna

During the last decade several applications of low-pressure diamond were developed. Main products are diamond heat-spreaders using its high thermal conductivity,diamond windows with their high transparency over a wide range of wavelengths and wear resitant tool coatings because of diamonds superhardness.

A short description of the most efficient diamond deposition methods (microwave, DC-glow discharge, plasma-jet and arc discharge) is given. The production and applications of diamond layers with high thermal conductivity will be described. Problems of reproducibility of diamond deposition, the influence of impurities, the heat conductivity in electronic packages, reliability and economical mass production will be discussed.

Workshop on Metal/Ceramic Composite Materials
for Functional Application
June 4-5, 1997, Vienna / Austria

THERMAL APPLICATIONS OF DIAMOND DEPOSITED BY LOW PRESSURE PROCESSES

R.Haubner, B.Lux

Institute for Chemical Technology of Inorganic Materials
Vienna University of Technology

hot-filament CVD diamond

electrical resistivity	thermal conductivity
specific resistivity: 10^8- $10^9 \Omega m$	k = 1200-1500 W/mK

diamond I, IIa: $>10^{18} \Omega m$
diamond IIb : 10^3 - $10^5 \Omega m$
SiO_2 : $10^{16} \Omega m$
BeO : 10^{11} - $10^{13} \Omega m$
Al_2O_3 : $>10^{10} \Omega m$

natural diamond of highest quality : k = 2000 - 2500 W/mK
Cu : k = 400 W/mK
AlN : k = 170 W/mK
Al_2O_3 : k = 30 W/mK

Reasons for CVD diamond with low quality:
- tantalum and nitrogen impurities
- crystal defects and graphite inclusions

Optimisation:
- high quality crystal growth
- microwave CVD
- heat treatments (reduce hydrogen content)
- surface finishing

Thermal Conductivity

Steady-state heating
- Heated Bar
- Heated Bar with Shield
- Two-Heater heated Bar
- Radiating Bar
- Insulated Plane

Thermal Diffusivity

Periodic heating
- End-heated Bar
- Spot heating on a Plate
- Spot heating on a Solid
- Plane and Line heating

Pulsed heating
- Annular heating
- Large-Area Surface heating
- Photothermal displacement spectroscopy at thermal gratings

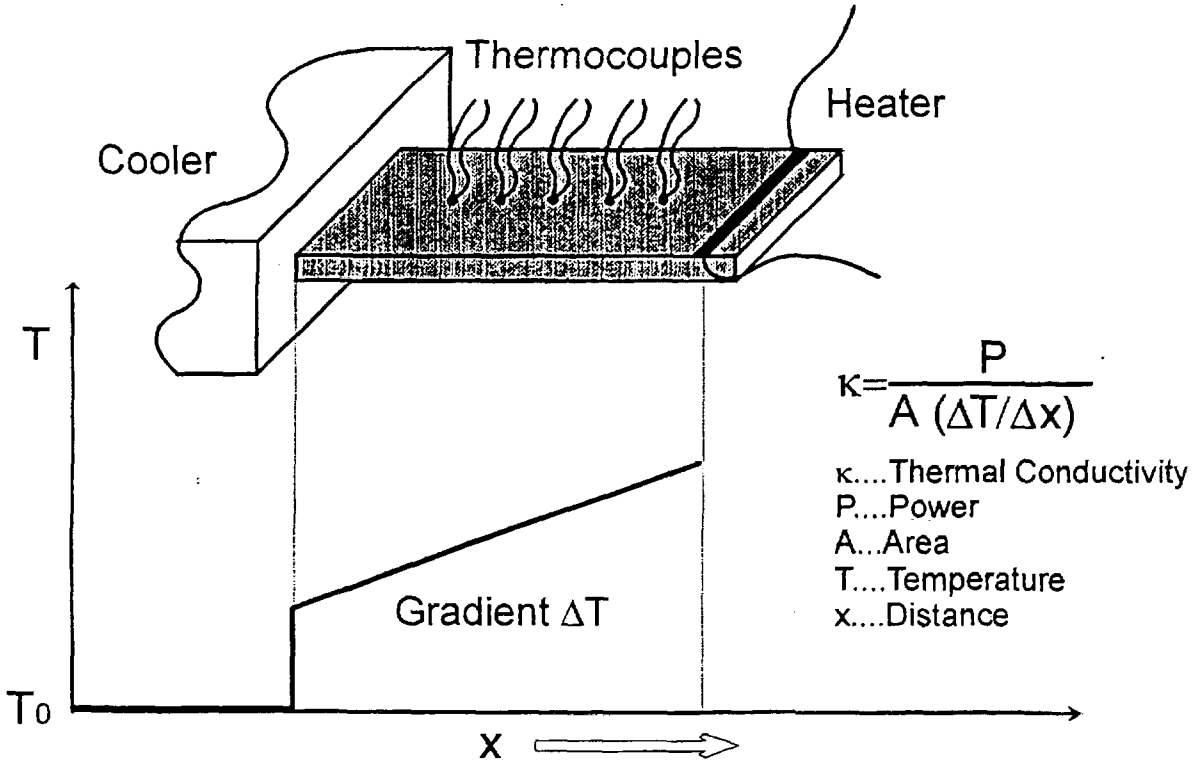
κ..... Thermal Conductivity
D..... Thermal Diffusivity
ρ..... Density
C..... Heat Capacity

$$\kappa = D * \rho * C$$

TU WIEN
Chemische Technologie anorganischer Stoffe
95-47

Thermal Conductivity - Diffusivity Measurement Techniques

HOLZER 1995



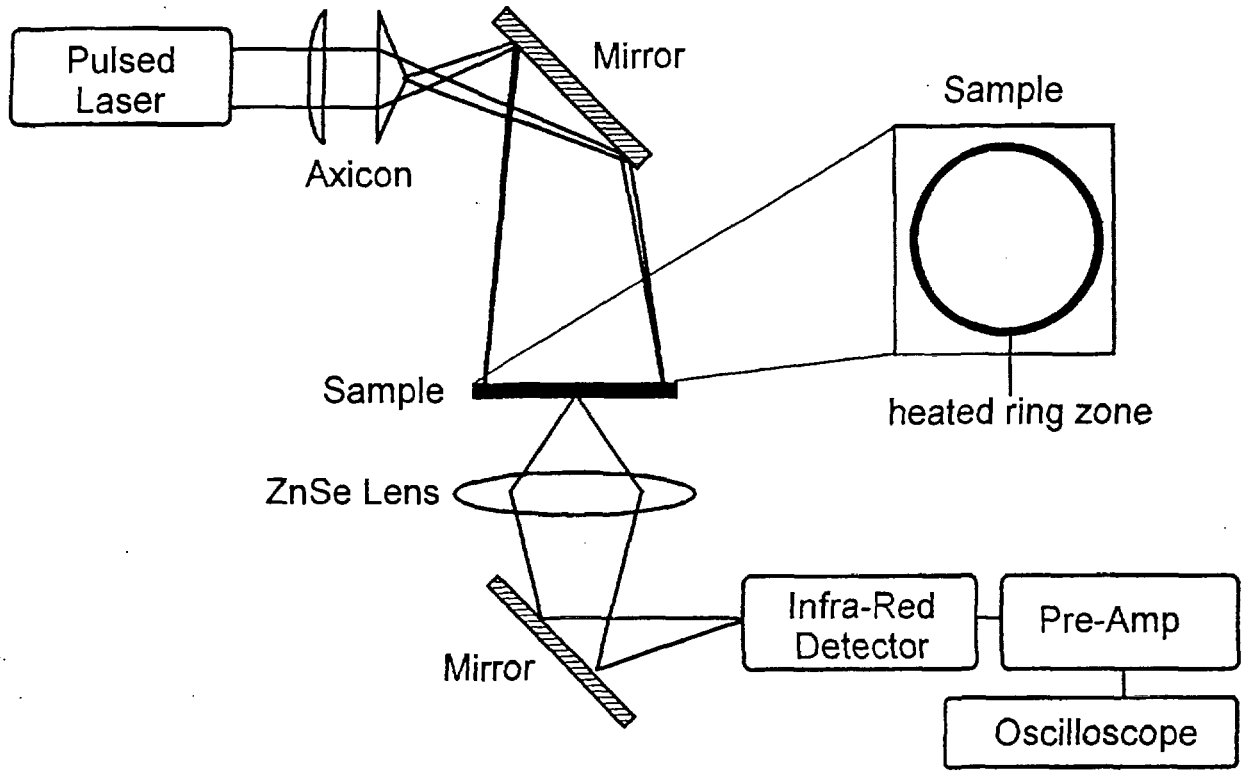
$$\kappa = \frac{P}{A\,(\Delta T/\Delta x)}$$

κ....Thermal Conductivity
P....Power
A...Area
T....Temperature
x....Distance

TU WIEN
Chemische Technologie anorganischer Stoffe
95-48

Thermal Conductivity Measurement (κ) Standard heated-bar Technique

HOLZER 1995

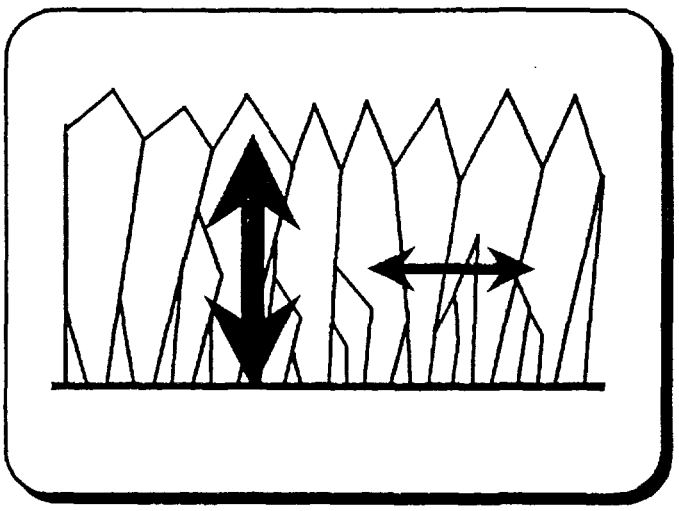


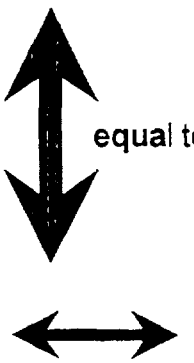
TU WIEN
Chemische Technologie anorganischer Stoffe
95-49

Thermal Diffusivity Measurement Converging Wave Technique

HOLZER 1995

heat flow directions **local thermal conductivity**





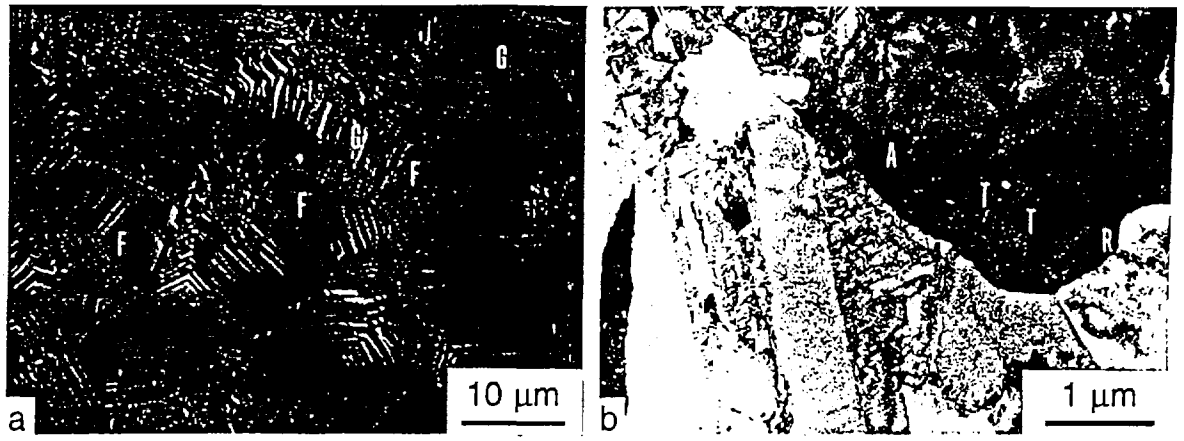
equal to diamond single crystals

up to 50 % lower

TU WIEN
Chemische Technologie anorganischer Stoffe
96-7

Graebner (1992)

CVD diamond with columnar structure: local thermal conductivity



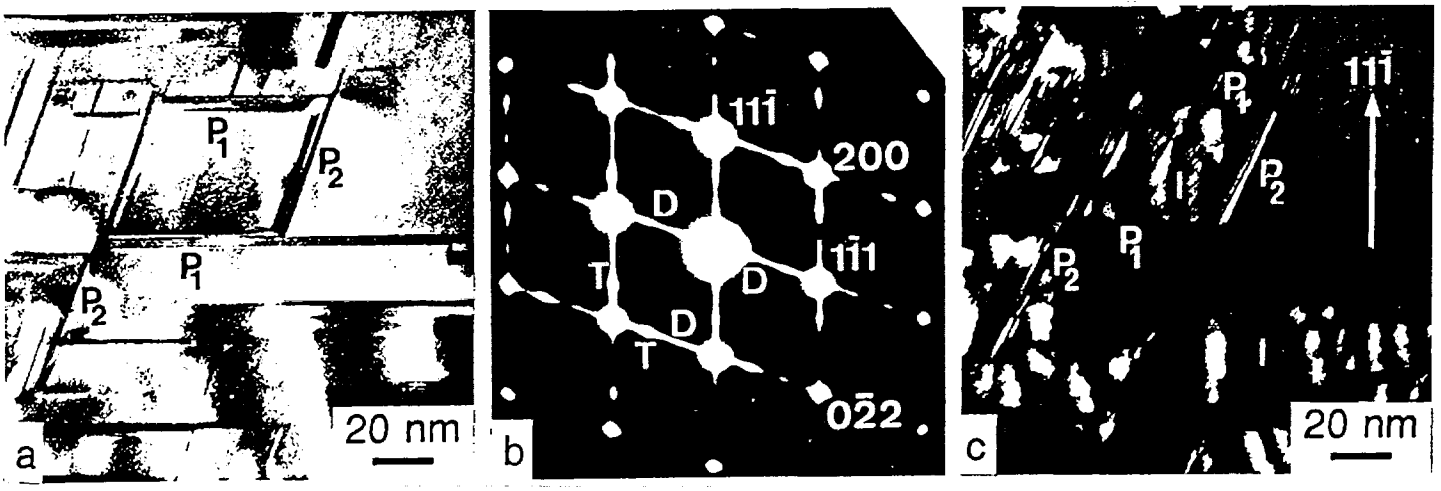
Layer surface
F: {100} facets
G: {111} covered with growth steps

TEM - plan view
T: Twin boundaries
R: Rough grain boundaries
A: Agglomerations of microtwins

TU WIEN
Chemische Technologie anorganischer Stoffe
93-113

TEM: Microstructure of a diamond layer showing large growth steps
(microwave CVD, central part of the deposition area)

D-A-CH
TU WIEN
Angewandte und Technische Physik



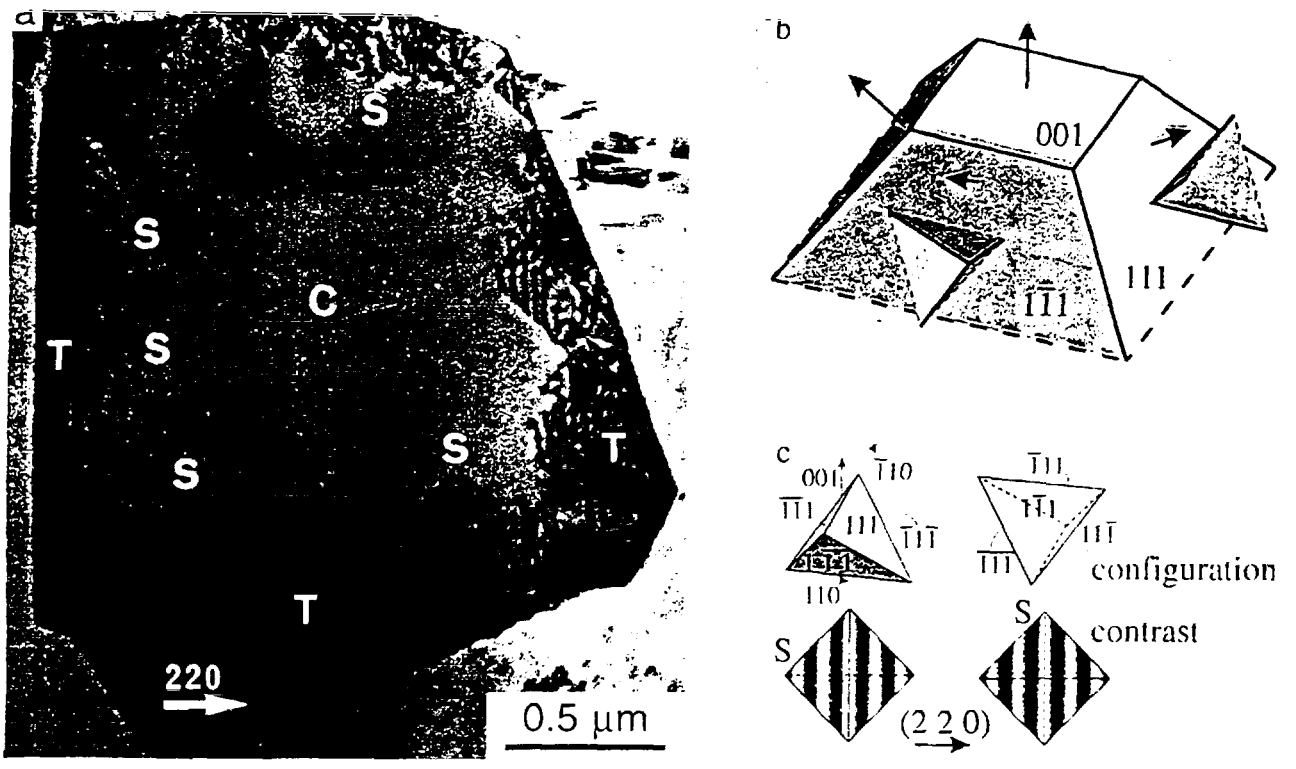
P_1, P_2: Twin lamellae parallel to [011]
I: Twin lamella inclined to [011]

T: Twin reflections
D: Double diffraction spots

TU WIEN
Chemische Technologie anorganischer Stoffe
93-115

TEM: Microstructure of CVD diamond
Twins parallel to all four {111} matrix planes

D-A-CH
TU WIEN
Angewandte und Technische Physik



C: twin free column
T: agglomerations of microtwins

S: starting points of twin growth

TU WIEN
Chemische Technologie anorganischer Stoffe
96 - 40

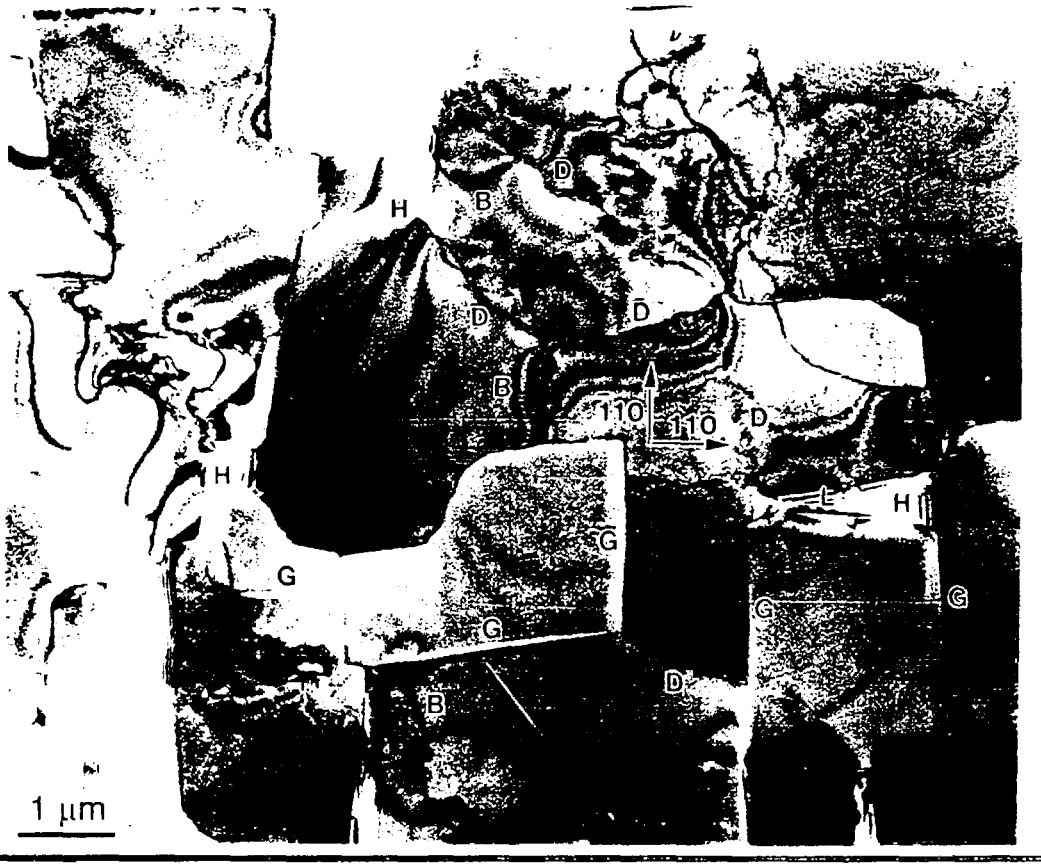
TEM of CVD DIAMOND

Nucleation of twin tetrahedra during ‹110› textured growth

(grown by P. Bachmann, Philips Research)

D-A-CI

TU WIEN
Angewandte un
Technische Phys



TU WIEN
Chemische Technologie anorganischer Stoffe
96 - 41

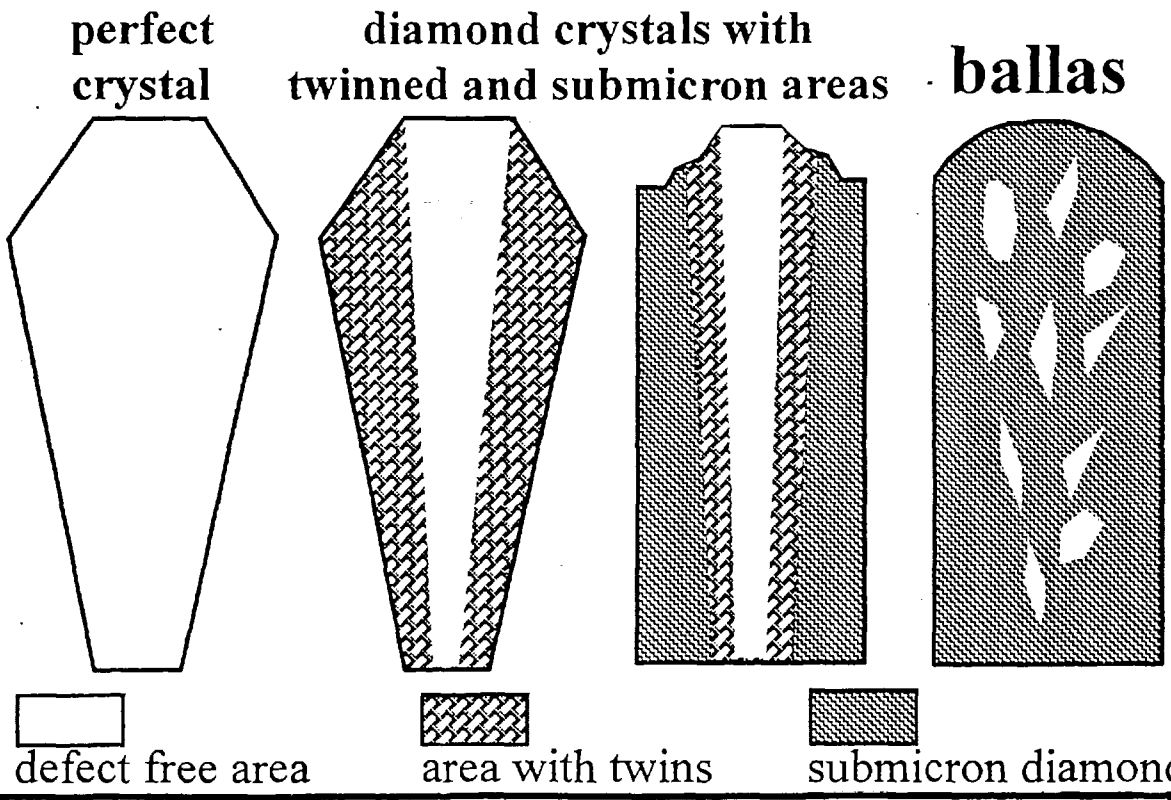
TEM of CVD DIAMOND High quality growth on Si

Plan-view of the layer surface region

(grown by R. Spitzl, Uni Wuppertal)

D-A-CI

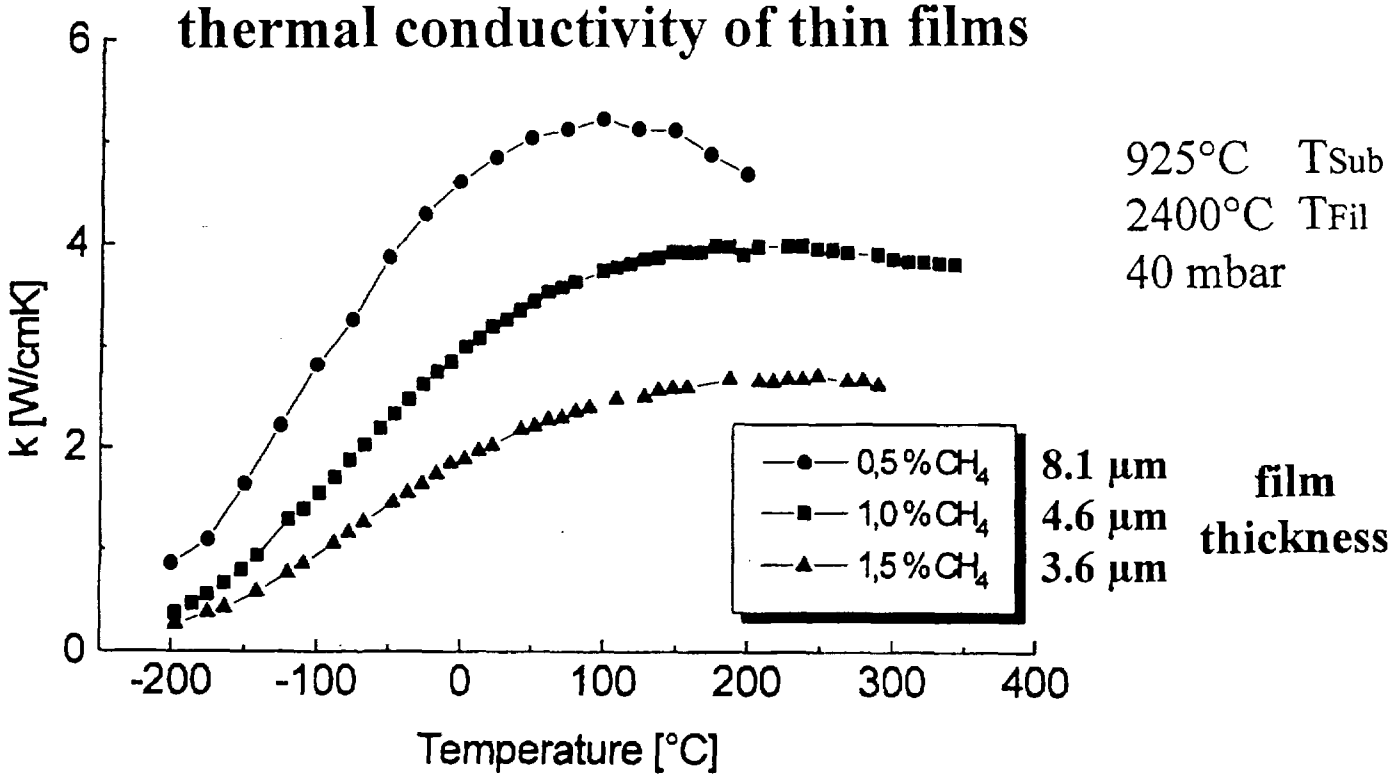
TU WIEN
Angewandte un
Technische Phys



TU WIEN
Chemische Technologie anorganischer Stoffe
97-4

Microstructures of CVD diamond: Distribution of defects in dimond crystals with various morphology

D-A-CH
WURZINGER
1996

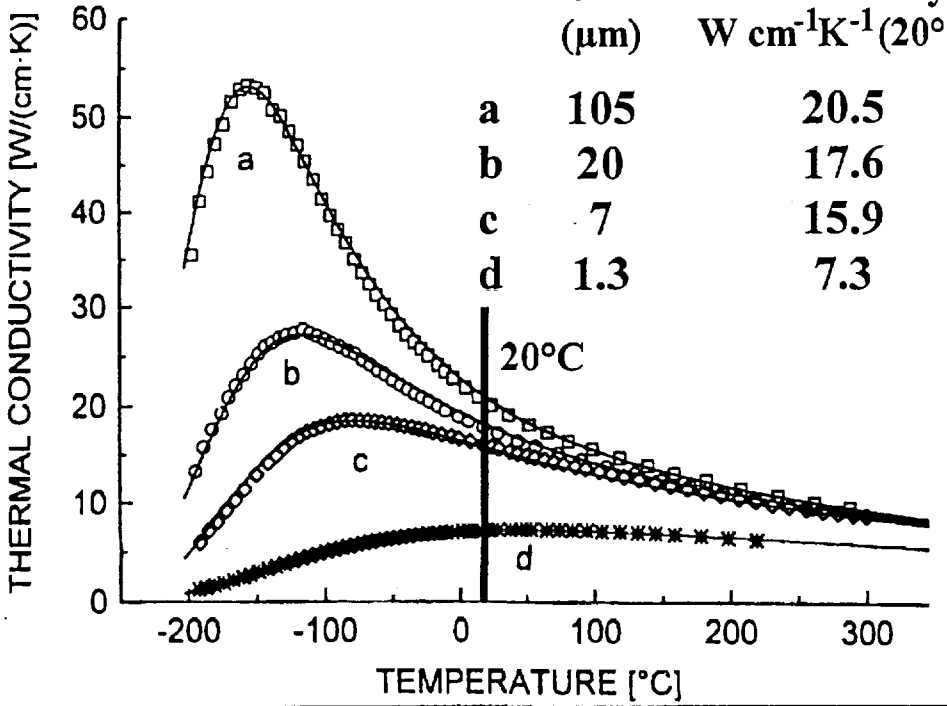


TU WIEN
Chemische Technologie anorganischer Stoffe
97-33

DIAMOND FILMS: Thermal conductivity of films deposited under different methane concentrations

E.Jansen et al.: Diamond and Related Materials 5 (1996) 648

	grain size (µm)	thermal conductivity W cm^{-1}K^{-1}(20°C)	layer thickness (µm)	nitrogen addition (ppm)
a	105	20.5	130	0
b	20	17.6	55	0
c	7	15.9	172	10
d	1.3	7.3	172	10

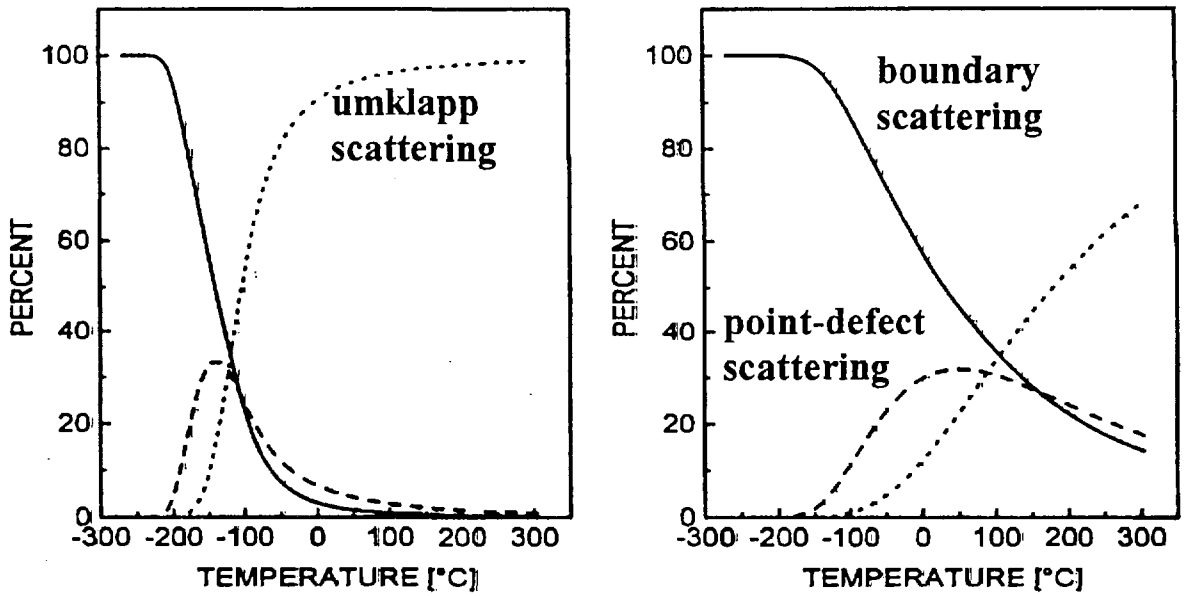


TU WIEN
Chemische Technologie anorganischer Stoffe
97-35

DIAMOND FILMS: Thermal conductivity of various diamond films

E.Wörner et al.: Diamond and Related Materials 5 (1996) 691

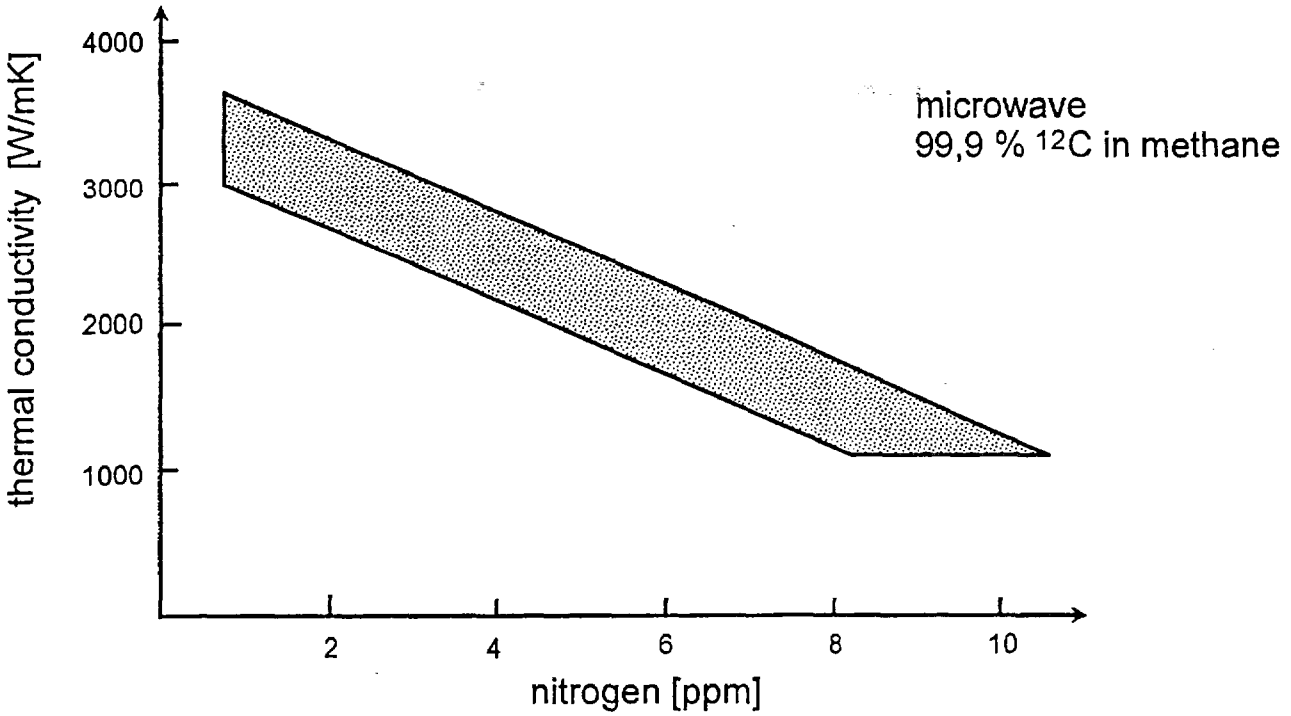
130	layer thickness (µm)	172
105	**grain size (µm)**	**1.3**
20.5	**W cm^{-1}K^{-1}(20°C)**	**7.3**



TU WIEN
Chemische Technologie anorganischer Stoffe
97-34

DIAMOND FILMS: Scattering mechanism influencing the thermal conductivity

E.Wörner et al.: Diamond and Related Materials 5 (1996) 691



Fujimori (1990)

TU WIEN
Chemische Technologie anorganischer Stoffe
96-8

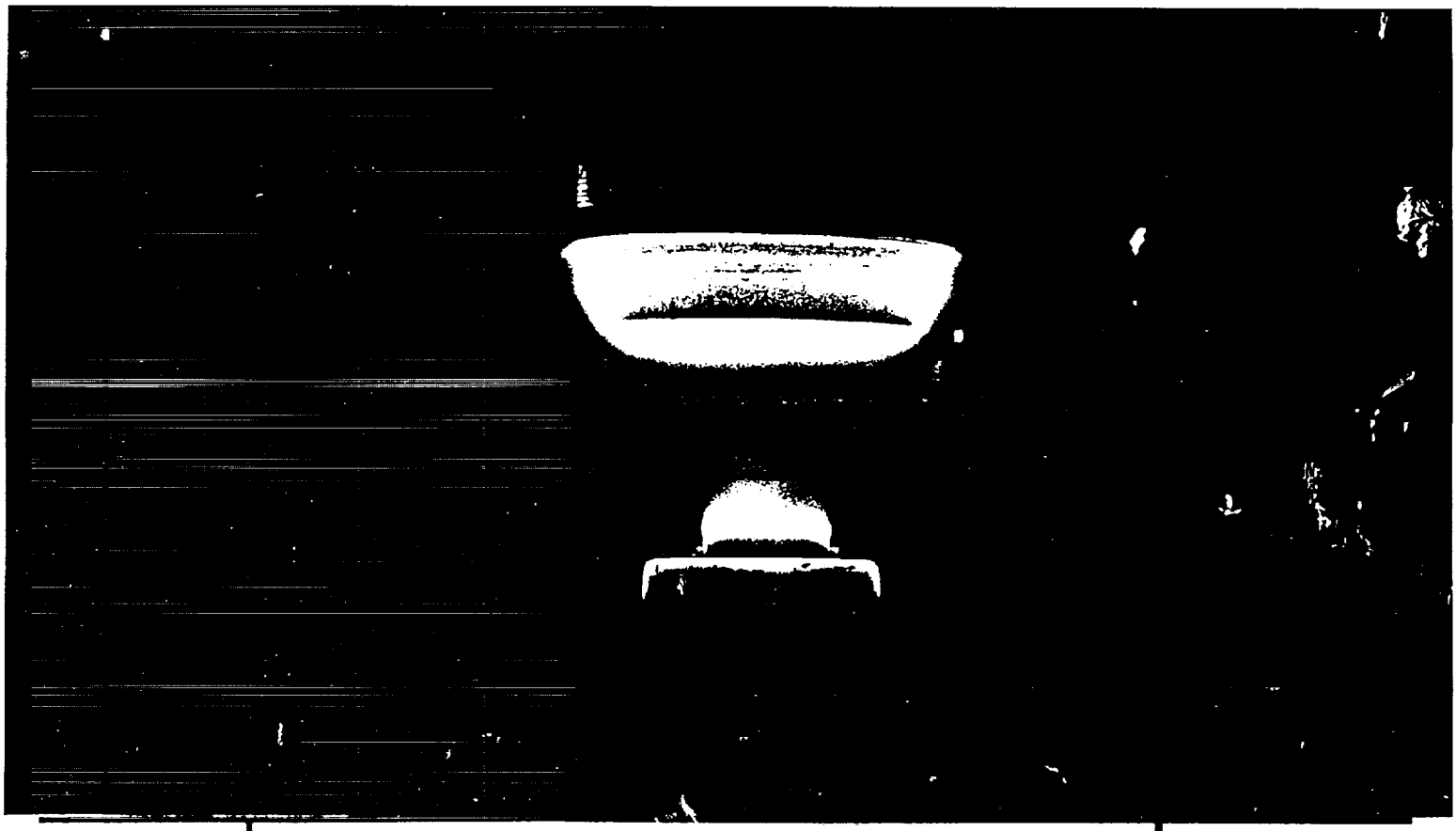
CVD diamond:
thermal conductivity vs. nitrogen as impurity

Grade	Growth Rate (µm/hr)	Lateral Thermal Conductivity (W/cm/K)	Resistivity (ohm -cm)	
			As-grown	Annealed
White	2	19.6 - 19.7	10^4 - 10^5	10^{13}-10^{14}
Grey	5	11.1 - 12.4	—	—
Black	13.5	8.9 - 9.6	10^4 - 10^5	$>10^{11}$

TU WIEN
Chemische Technologie anorganischer Stoffe
96-18

Diamond: Properties of diamond deposited by microwave Plasma-CVD

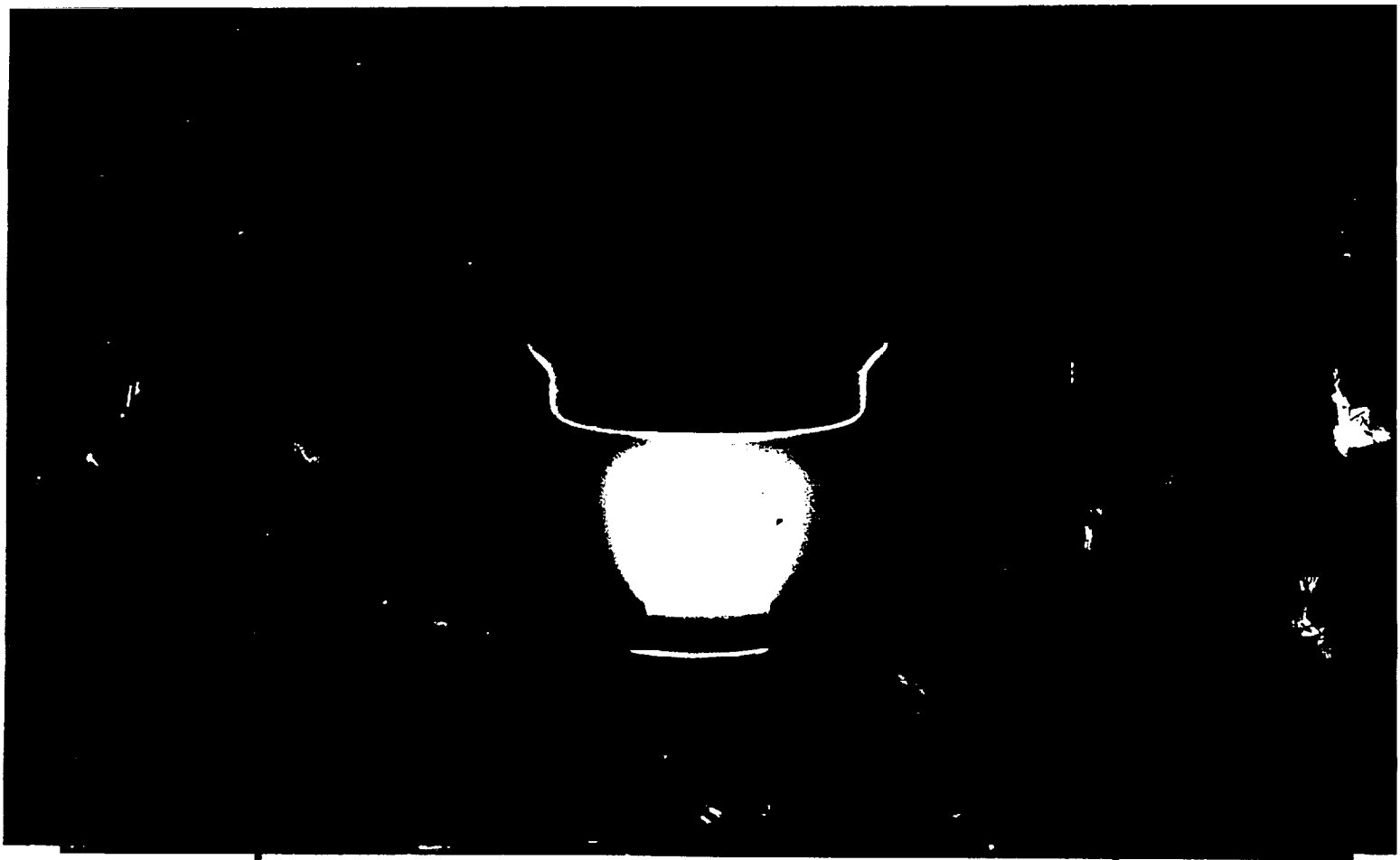
M.C.Costello et al: presented at Diamond Films 94, Il Ciocco, Italy



TU WIEN
Chemische Technologie anorganischer Stoffe
94-307

DC-Glowdischarge: Striations at low gas pressure

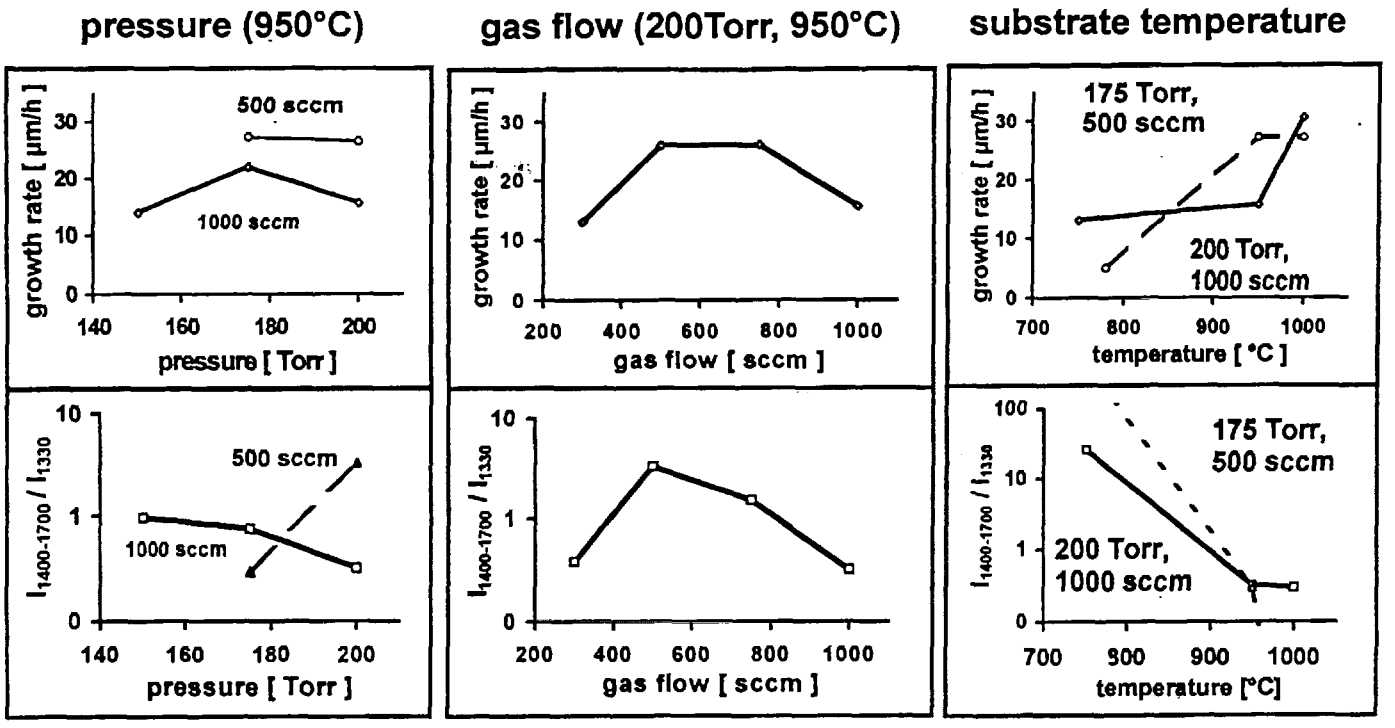
D-A-CH
HARTMANN
1994



TU WIEN
Chemische Technologie anorganischer Stoffe

DC-Glowdischarge: Discharge at typical deposition conditions

D-A-CH
HARTMANN
1994

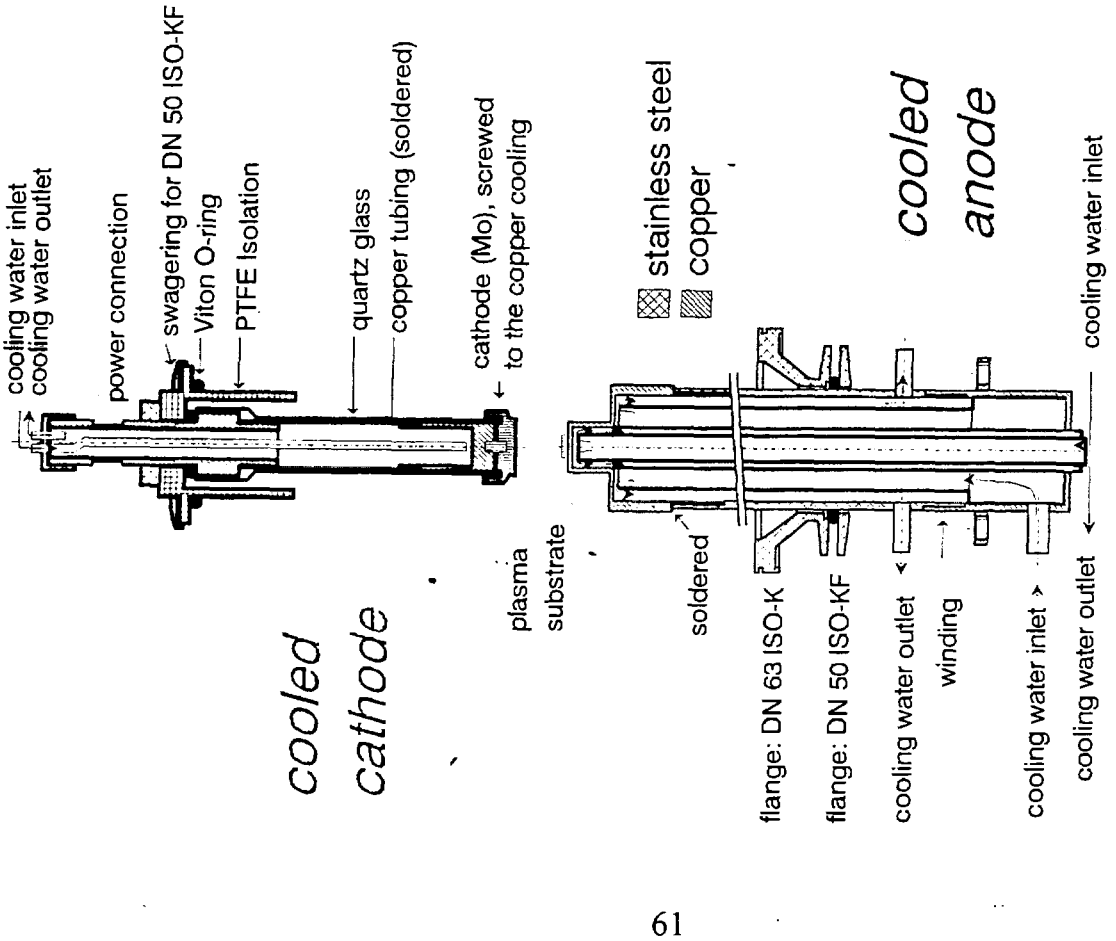


TU WIEN
Chemische Technologie anorganischer Stoffe
96-211

DC-Glow discharge diamond CVD
Variation of process parameters:
Growth rate and correlated phase purity (Raman)

(4% CH_4/H_2, 5kW, 3cm² deposition area, Mo substrate)

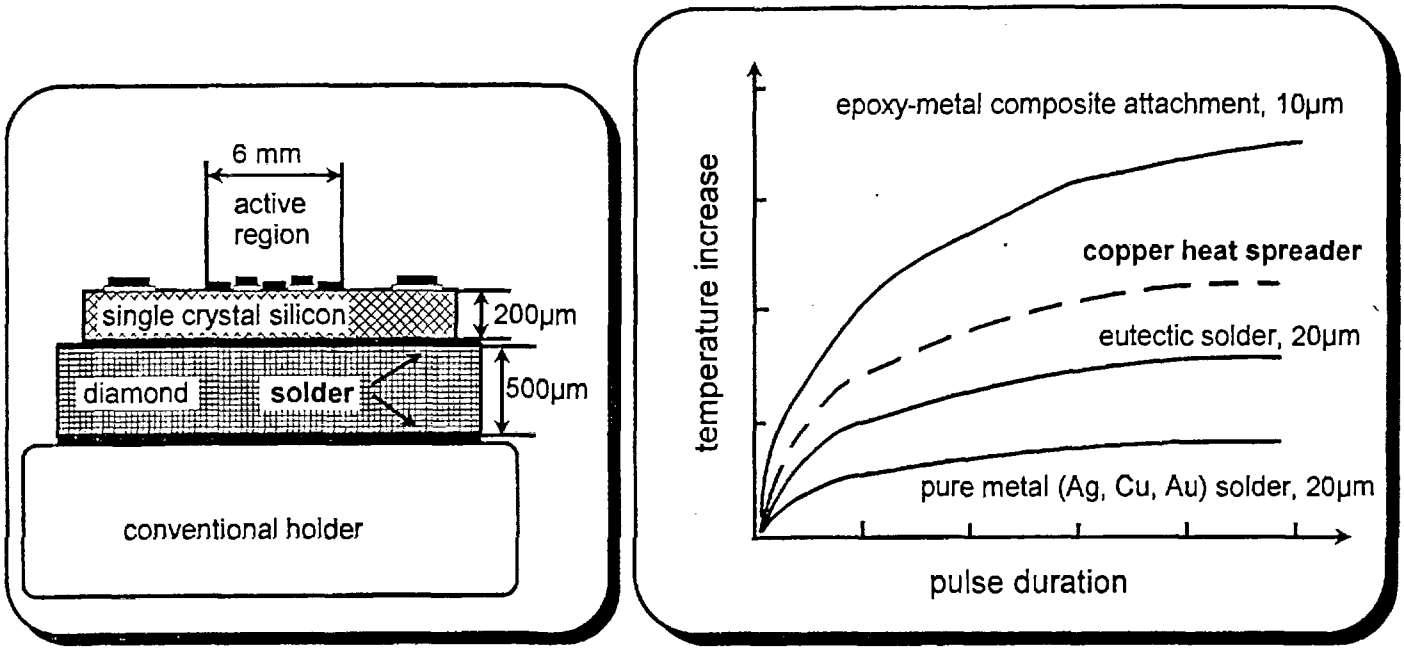
D-A-CH
HARTMANN
1996



D-A-CH
HARTMANN
1994

DC-Glowdischarge
Electrodes construction

TU WIEN
Chemische Technologie anorganischer Stoffe
94-304

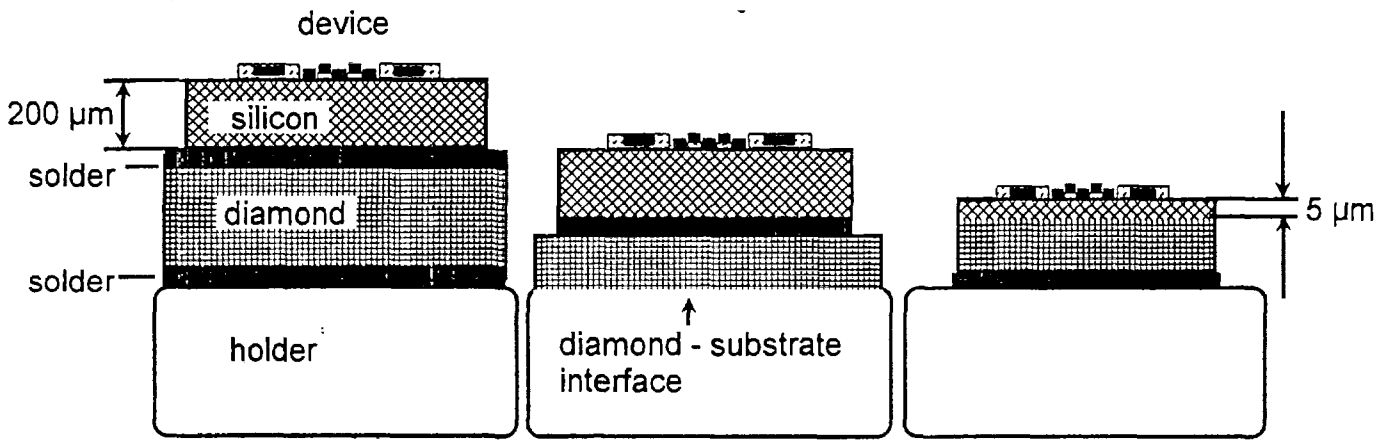


Solder influence on thermal resistance

TU WIEN
Chemische Technologie anorganischer Stoffe
96-9

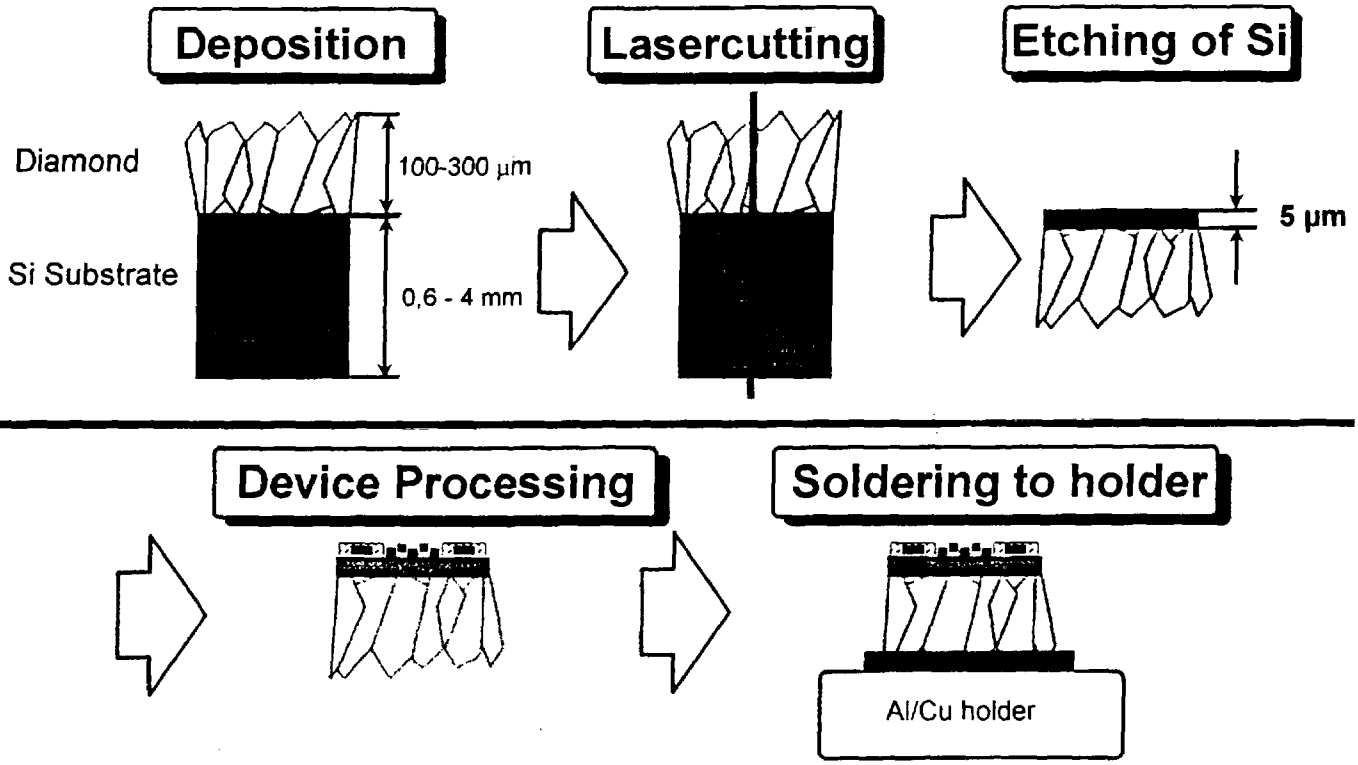
Zachai (1994)

Freestanding CVD diamond:
conventional heat spreader for power transistor



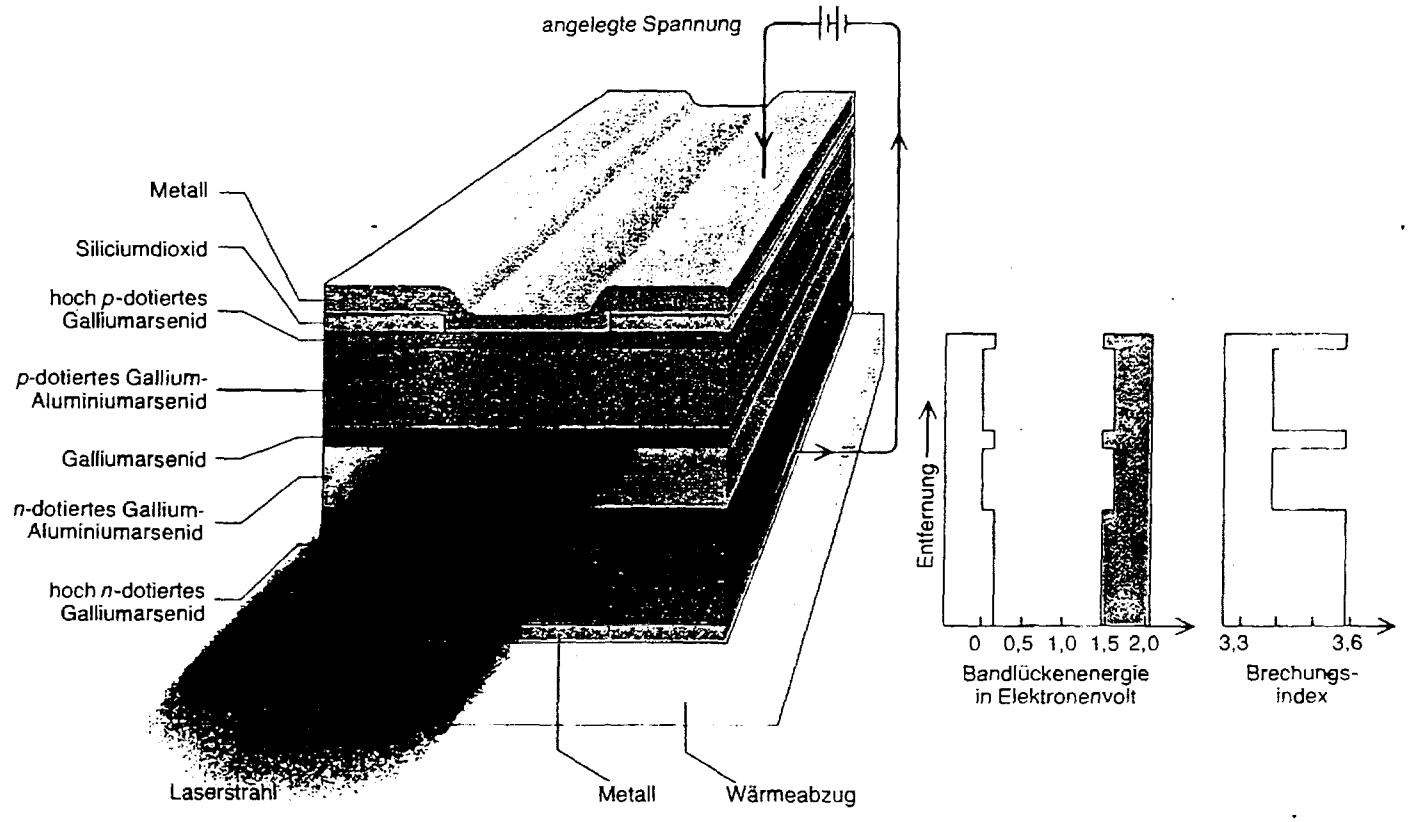
TU WIEN
Chemische Technologie anorganischer Stoffe
96-22

CVD diamond heat spreader



TU WIEN
Chemische Technologie anorganischer Stoffe
96-11

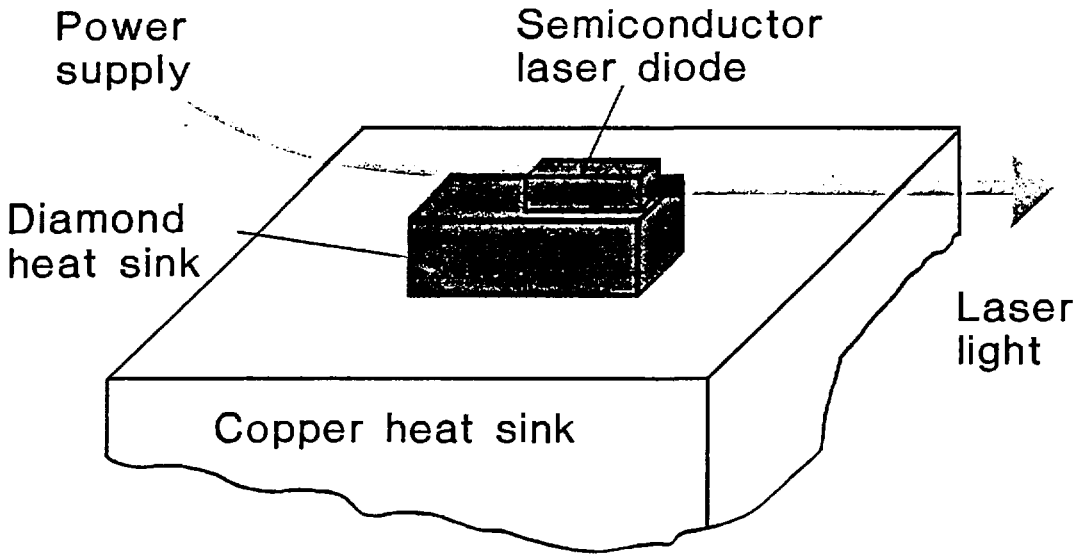
CVD diamond:
advanced **"silicon on diamond"** technology

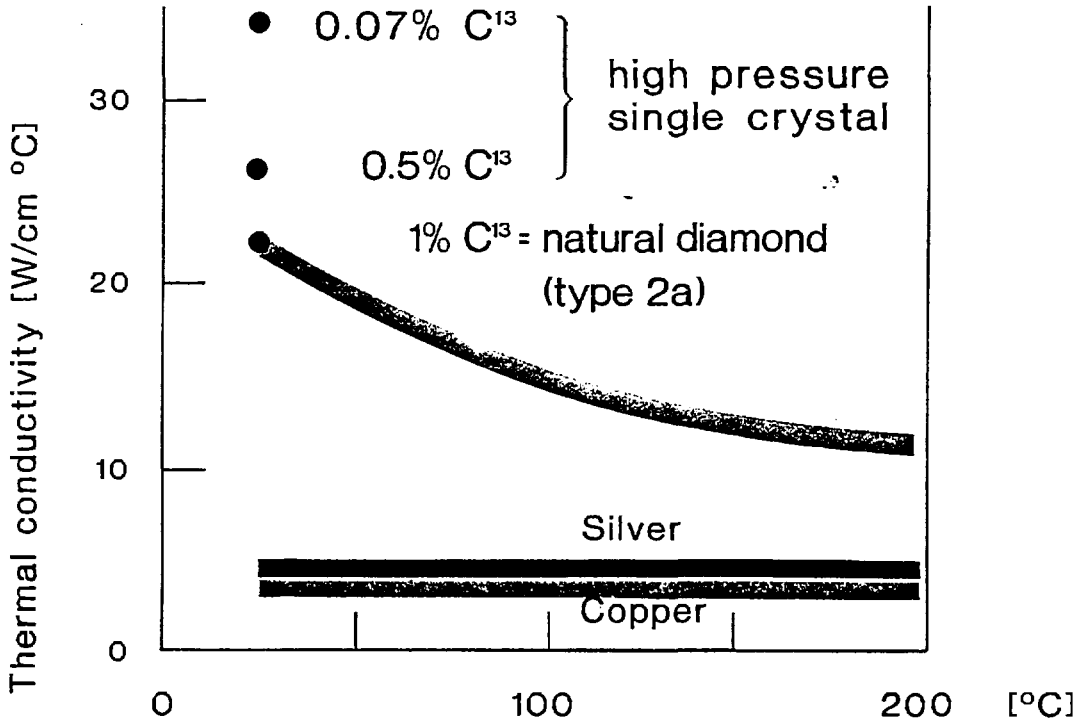


TU WIEN
Chemische Technologie anorganischer Stoffe
96 - 77

Schichtstruktur eines Halbleiterlasers

Spektrum der Wissenschaft, Neue Werkstoffe 1987





TU Wien
Chemische Technologie anorganischer Stoffe
91 - 64

Single Crystal Diamonds as Heat Sinks

P. K. BACHMANN, R. MESSIER 1989