Recent Progress in the Growth of Heteroepitaxial Diamond for Detector Applications

Matthias Schreck[1], Michael Mayr[1], Michael Träger[3], Mladen Kis[3], Patrik Ščajev[4], Eleni Berdermann[3], Stefan Gsell[2], Martin Fischer[2], Thomas Roth[5], Jan Grünert[5], Wolfgang Freund[5], Anders Madsen[5]

[1]*Universität Augsburg, Institut für Physik, D-86135 Augsburg*
[2]*Augsburg Diamond Technology GmbH, D-86159 Augsburg*
[3]*GSI Helmholtzzentrum für Schwerionenforschung, D-64291 Darmstadt*
[4]*Vilnius University, LT-10257 Vilnius (Lithuania)*
[5]*European X-Ray Free-Electron Laser Facility, Holzkoppel 4, D-22869 Schenefeld*

OUTLINE

Part I: Progress in Heteroepitaxial Growth

- The layer system Dia/Ir/YSZ/Si
- Recent progress in dislocation density
- Recent progress in size
- Outlook for ELO

Part II: Characterization

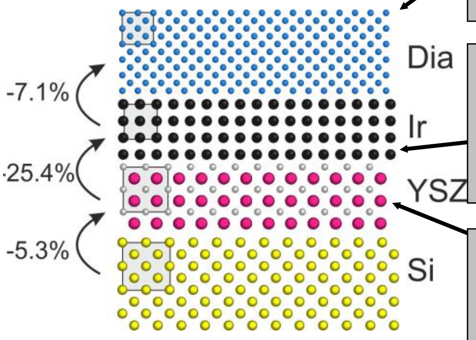
- Methods: Free carrier absorption, CCE,TCT,
- Trapping, carrier lifetime
- Correlation with dislocation density

THE HETEROEPITAXIAL MULTILAYER SYSTEM Dia/Ir/YSZ/Si

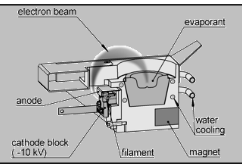
Microwave Plasma CVD:

(1) Bias enhanced nucleation (BEN)

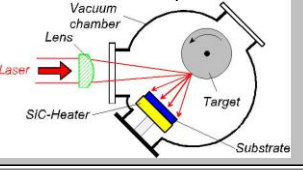
(2) MWPCVD diamond growth



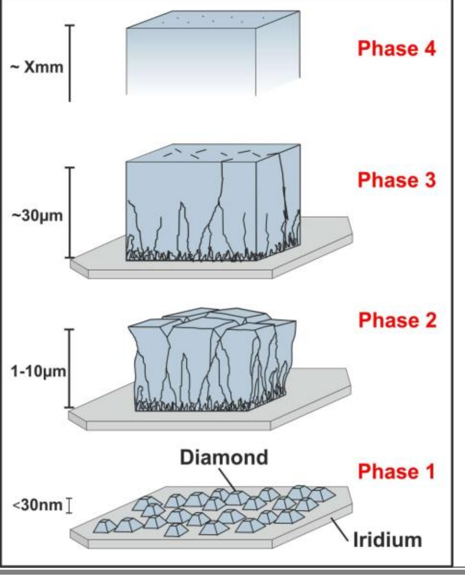
E-beam evaporation



Pulsed Laser Deposition

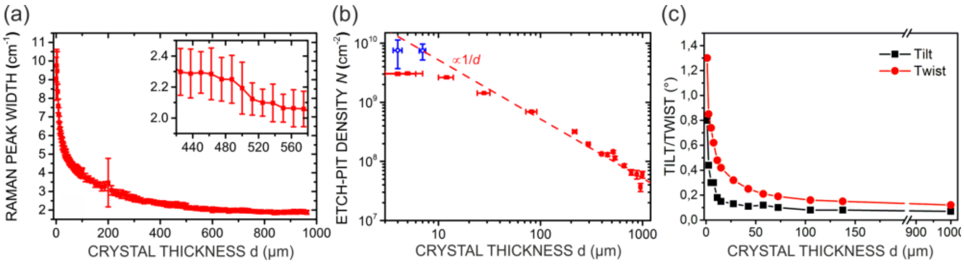


EVOLUTION OF THE DEFECT STRUCTURE



$3 \times 10^{11} cm^{-2}$

VARIATION OF CRYSTAL QUALITY WITH FILM THICKNESS



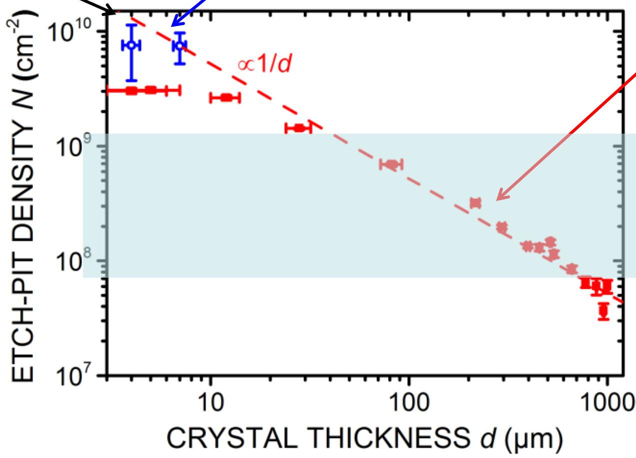
Raman line width	Dislocation density	Mosaic spread
>10 cm^{-1} ➔ ~1.8 cm^{-1}	>$10^{10}$$cm^{-2}$ ➔ <$10^{8}$$cm^{-2}$	1 – 1.5° ➔ ~ 0.1°

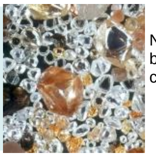
VARIATION OF THE DISLOCATION DENSITY WITH FILM THICKNESS

Extremely high dislocation density after nucleation

Data points from TEM measurements

Data points from etching experiments





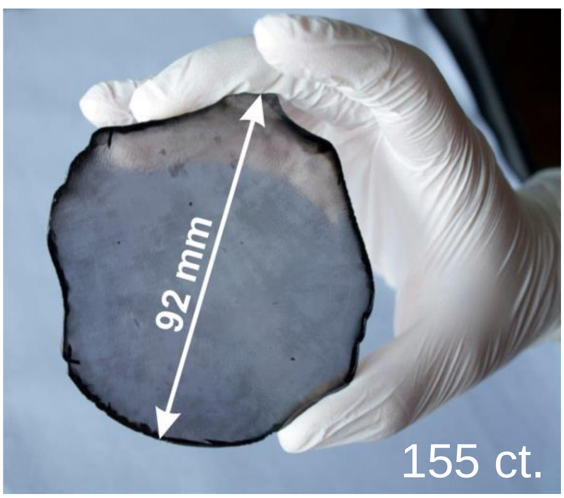
Natural IIa, brown - colourless

R.S. Balmer et al.: *Chemical vapour deposition synthetic diamond: material, technology and applications* J. Phys.: Condens. Matter **21** (2009) 364221.

SAMPLE SIZE

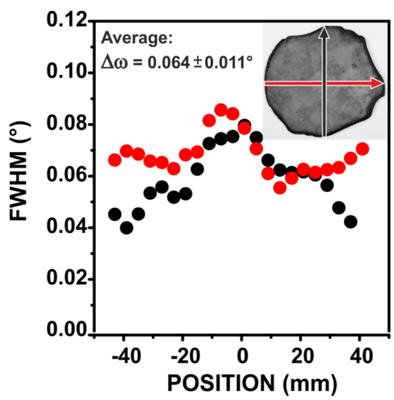
Sample size

STATE OF THE ART IN TERMS OF SIZE AND STRUCTURE



M. Schreck, S. Gsell, R. Brescia, M. Fischer, Sci. Rep. 7, 44462 (2017).

XRD Mosaic spread



XRD $\Delta\omega = 0.064 \pm 0.011°$

$\Delta\varphi = 0.12 \pm 0.04°$

Raman FWHM = 1.75 ± 0.07 cm^{-1}

AUGSBURG DIAMOND TECHNOLOGY GmbH (AuDiaTec)

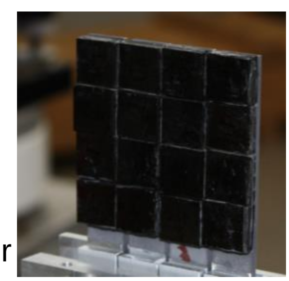
Office:	Am Technologiezentrum 5 86159 Augsburg
Foundation:	11/2015
Founders:	M. Fischer, S. Gsell, M. Schreck
CEO:	M. Fischer, S. Gsell
Business administration:	A. Rieger

APPLICATIONS: MECHANICAL & OPTICAL & NEUTRON MONOCHROMATORS

Cutting tools (inserts) for ultraprecision machining

Windows

Neutron monochromator



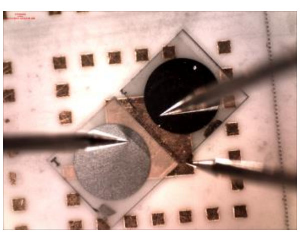
APPLICATIONS

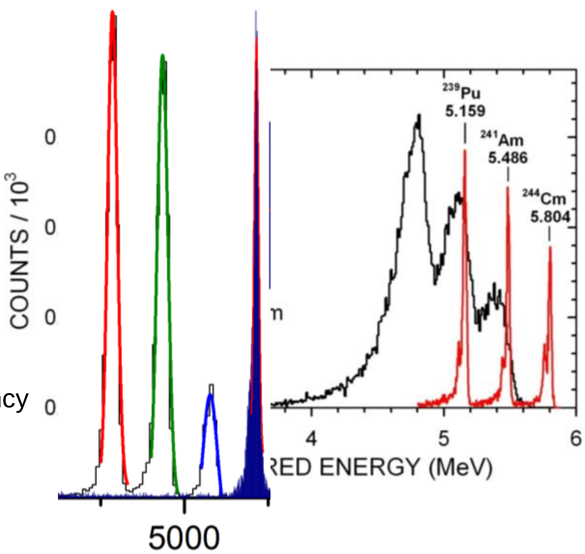
Part II

Characterization:

How crucial is the role of dislocations?

TRACKING & TIMING DETECTORS IN PARTICLE PHYSICS

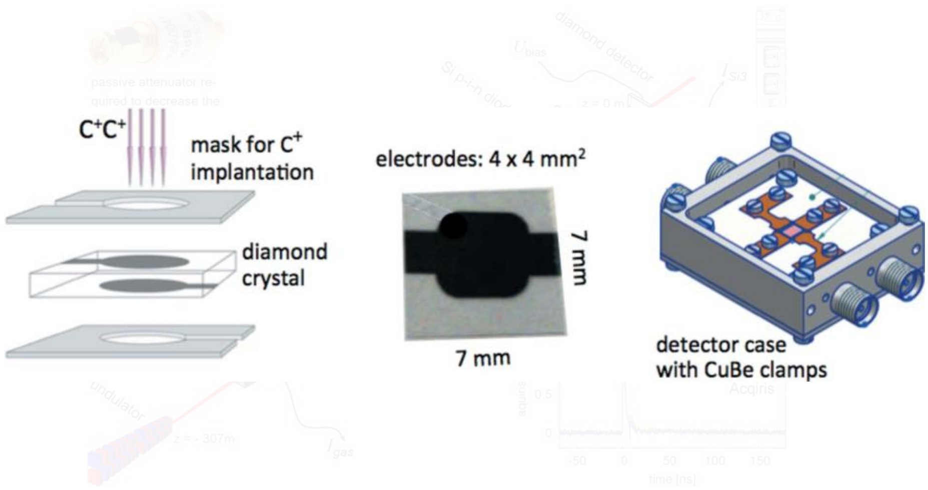




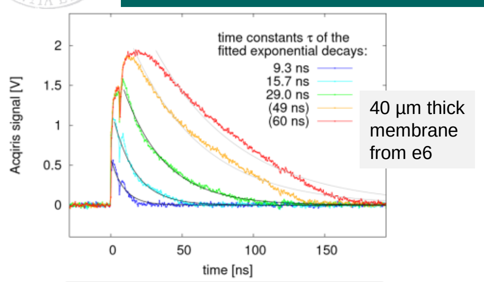
C. Stehl et al., *Appl. Phys. Lett.* **103,** 151905 (2013)

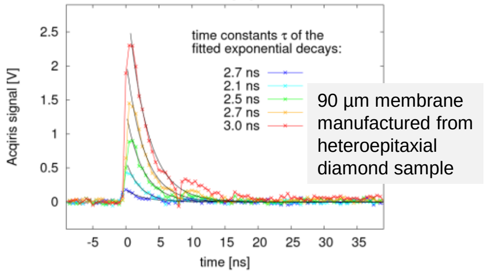
Charge collection efficiency
for holes: > 90%
for electrons: << 50%

PULSE ENERGY MONITOR
@ FREE ELECTRON LASER (XFEL)



PULSE ENERGY MONITOR
@FREE ELECTRON LASER (XFEL)





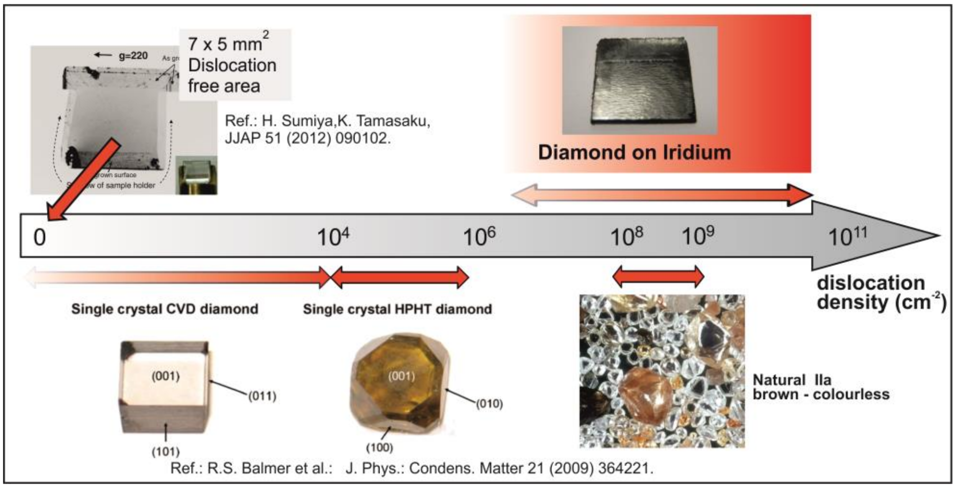
Roth et al. J. Synchrotron Rad. **25**, 177 (2018)

Measurements performed @Linac Coherent Light Source, SLAC National Accelerator Laboratory

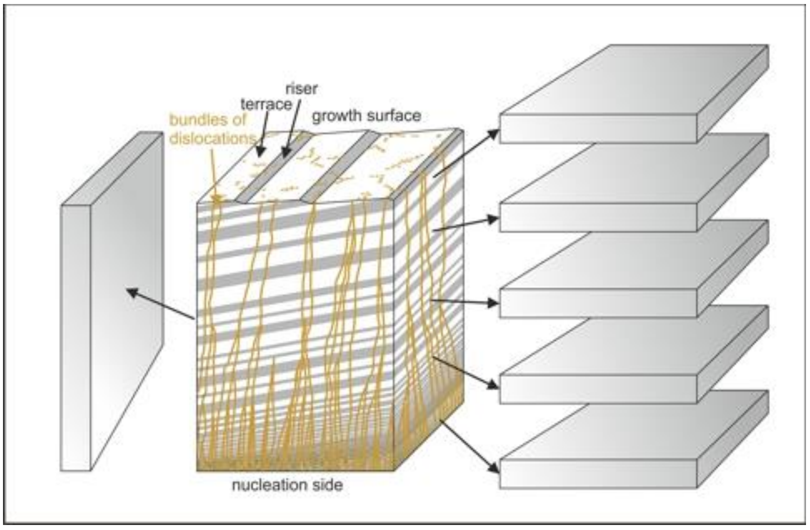
➔ Signal limited by
- Space charge effects
- Carrier lifetime

Solution:
- Higher field strength
- Parallel capacitor

STATE OF THE ART & POTENTIAL FOR FURTHER IMPROVEMENT



SYSTEMATIC VARIATION OF DISLOCATION DENSITY



ELECTRONIC PROPERTIES

Universität Augsburg University

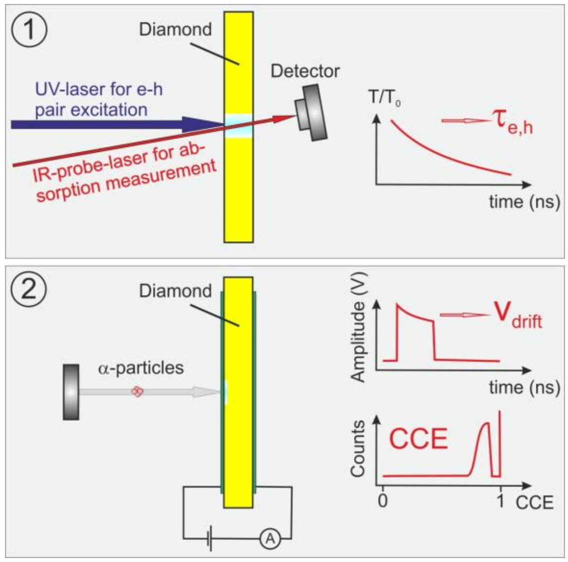
1) Free **C**arrier **A**bsorption (FCA)

P. Ščajev (Vilnius)

2a) Transient **C**urrent **T**echnique (TCT)

2b) Charge **C**ollection **E**fficiency (CCE)

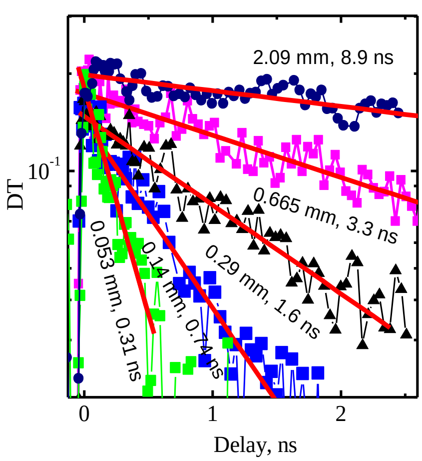
M. Träger, M. Kiš (GSI)



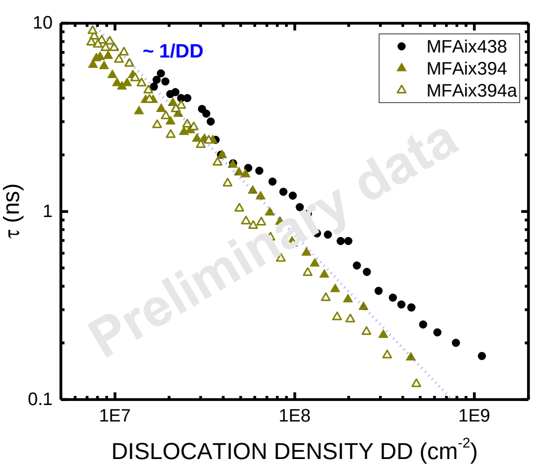
FREE CARRIER ABSORPTION (FCA)

Universität Augsburg University

Differential Transmissivity DT

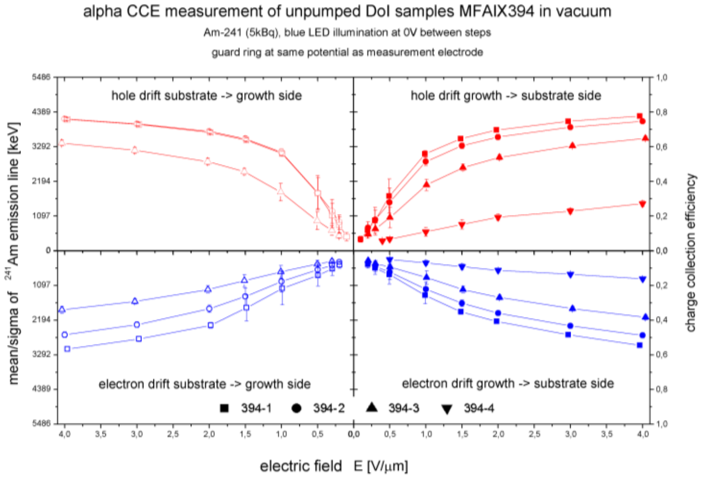


Lifetime vs. dislocation density

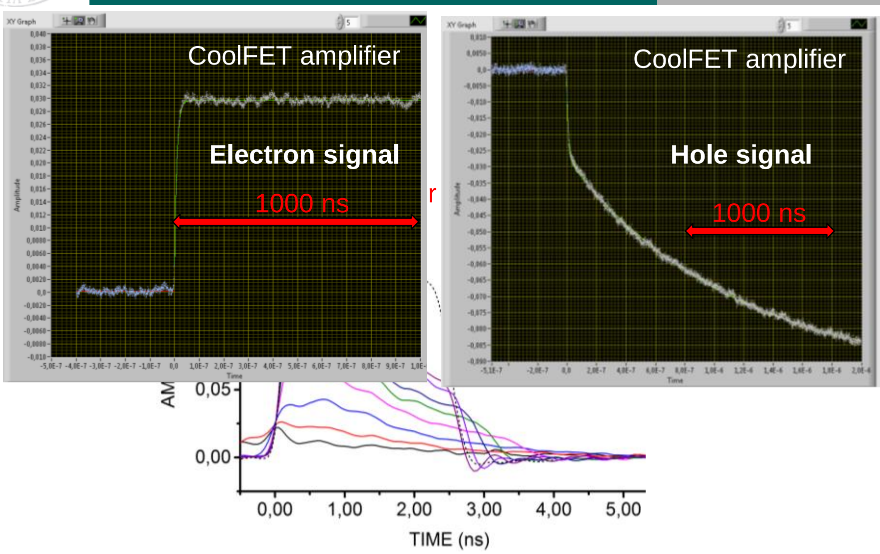


CHARGE COLLECTION EFFICIENCY MEASUREMENTS

Measurements with high-impedance charge-sensitive amplifier (CSA)
(integration time ~ 10 µs)



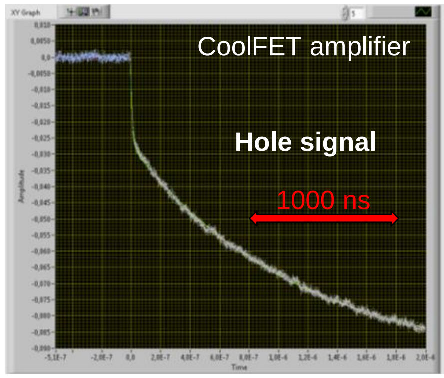
TCT MEASUREMENTS



TCT MEASUREMENTS WITH COOLFET AMPLIFIER

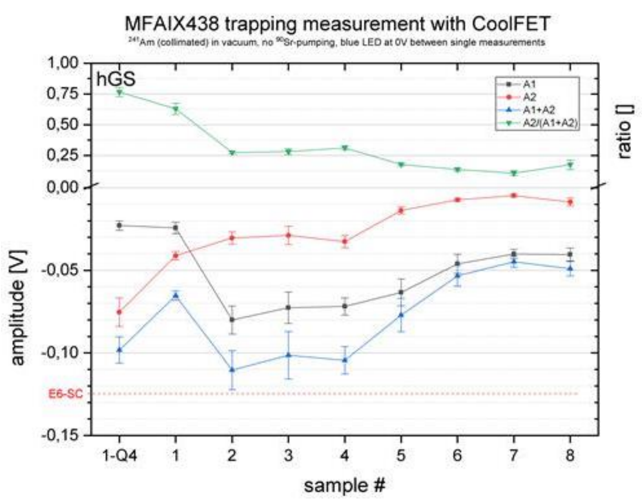
Hole signal generated before any trapping

Signal generated by holes after release from traps



Estimation: ~1 ppb of compensated boron (i.e. B^- traps)

TCT MEASUREMENTS WITH COOLFET AMPLIFIER



TRAPPING CENTERS

Charged trap: Coulomb energy of point charge

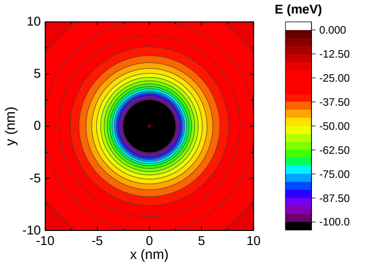
Capture cross sections (typical values):

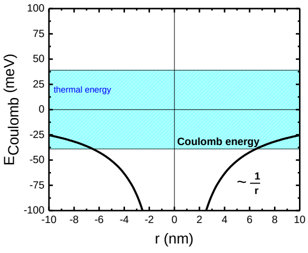
Neutral traps ~10^{-16} cm^2

Charged traps ~10^{-12} cm^2 (attractive)

Charged traps ~10^{-19} cm^2 (repulsive)

R.H. Bube: Electrons in Solids, Academic Press, 1988

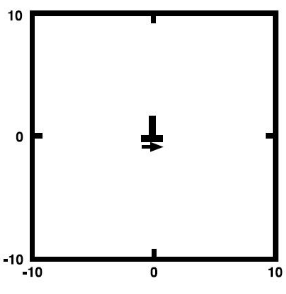


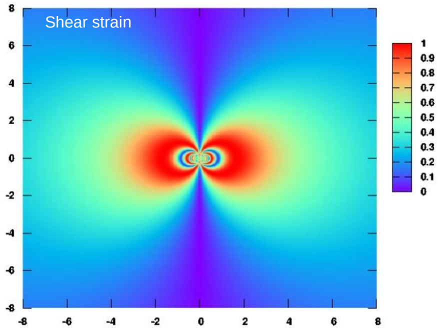


STRESS FIELD AROUND DISLOCATIONS

Strain / stress around an edge dislocation

Edge dislocation





H. Pinto and R. Jones: *Theory of the birefringence due to dislocations in single crystal CVD diamond*, J. Phys.: Condens. Matter 21 (2009) 364220

The stress field around the dislocations also modifies valence and conduction band edge ➔ trapping potential

SUMMARY AND CONCLUSIONS

Universität Augsburg University

- Ir/YSZ/Si substrates + BEN + extended growth
  ➔ Dia(001) with high structural quality
- Wafer scale diamond(001): 155 ct, Φ ~ 3.5”
- Material available via Augsburg Diamond Technology GmbH
- Recent progress in dislocation density reduction
- Improved understanding of dislocations as charge carrier traps

MANY THANKS TO ....

Universität Augsburg University

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GSI

DFG Deutsche Forschungsgemeinschaft

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THANKS FOR YOUR ATTENTION