ESRF

Single Crystal, CVD Diamond for *Synchrotron* Beam Monitoring

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invaluable help from...

E. Berdermann, M. Pomorski

Detector Group, GSI-Darmstadt

Overview

1. ESRF X-ray synchrotron source
2. X-beam monitoring requirements and diamond
3. Recent measurements in X beams at ESRF
4. Conclusions: critical issues remaining…

ESRF X-ray source characteristics

Brilliance
(photons/s/mm^2/mrad^2/0.1%BW)

Free electron lasers

Diffraction limit

Third generation

ESRF (future)

ESRF (2000)

ESRF (1994)

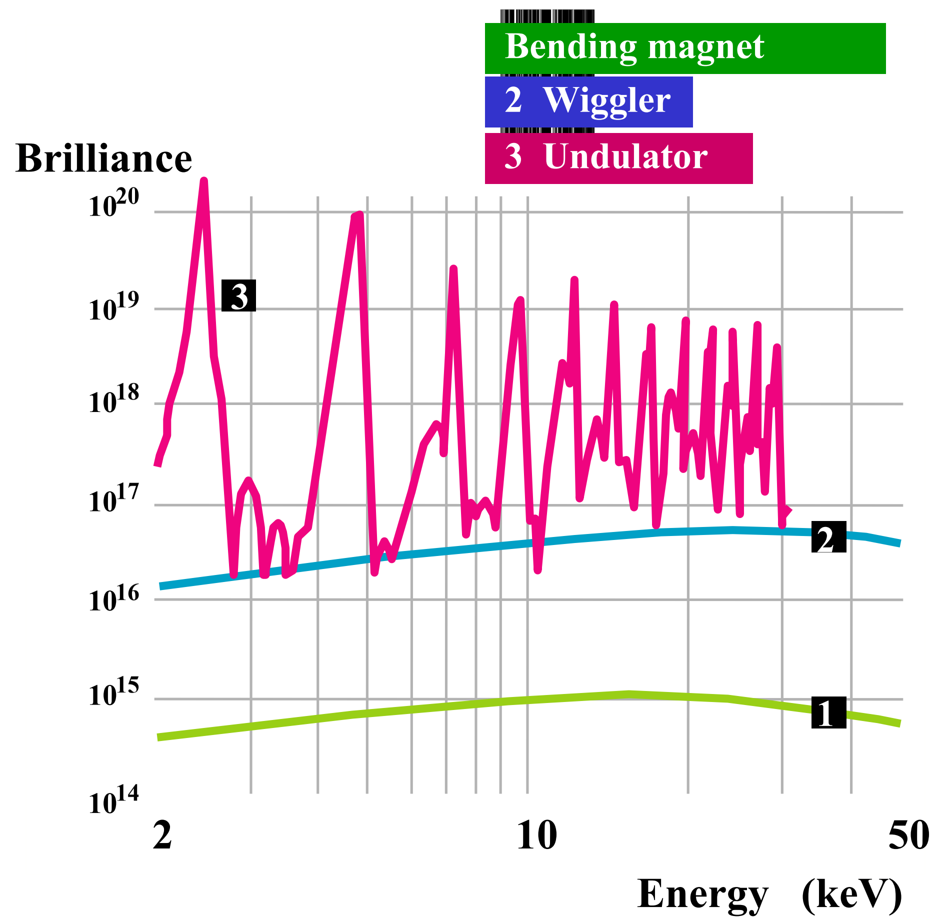
Second generation

First generation

X-ray tubes

1900 1920 1940 1960 1980 2000

Years



Synchrotron Beam Monitoring

(need intensity, position/vector ...and shape)

Synchrotron beam size at samples now
~100µm to <1µm (<50nm state of the art focussing)

Required beam stability ~10% of beam FWHM

Beam *intensity* measurements require <1%...0.1%
(relative) accuracy & linearity,
for *sampling* times <0.1 ... 10 secs

X-ray fluxes:

~10^9 photons/1µm^2/s ... 10^{13}photons/(100µm)^2/s

photon energies ~ 1 ... 50 keV

=> max. power: ~ mW (monochromatic beam)

But >100W in 'white' beam!!

why diamond?

Z = 6, => low specific X-ray absorption/beam scattering

High charge carrier saturation velocity (~$3x10^7$cm/s),
low dielectric constant (5.5)

-> fast pulse response (~nsec in practical devices)

wide bandgap energy (5eV), excellent thermal/mechanical properties

-> high heat load, 'white' beam monitoring possibility

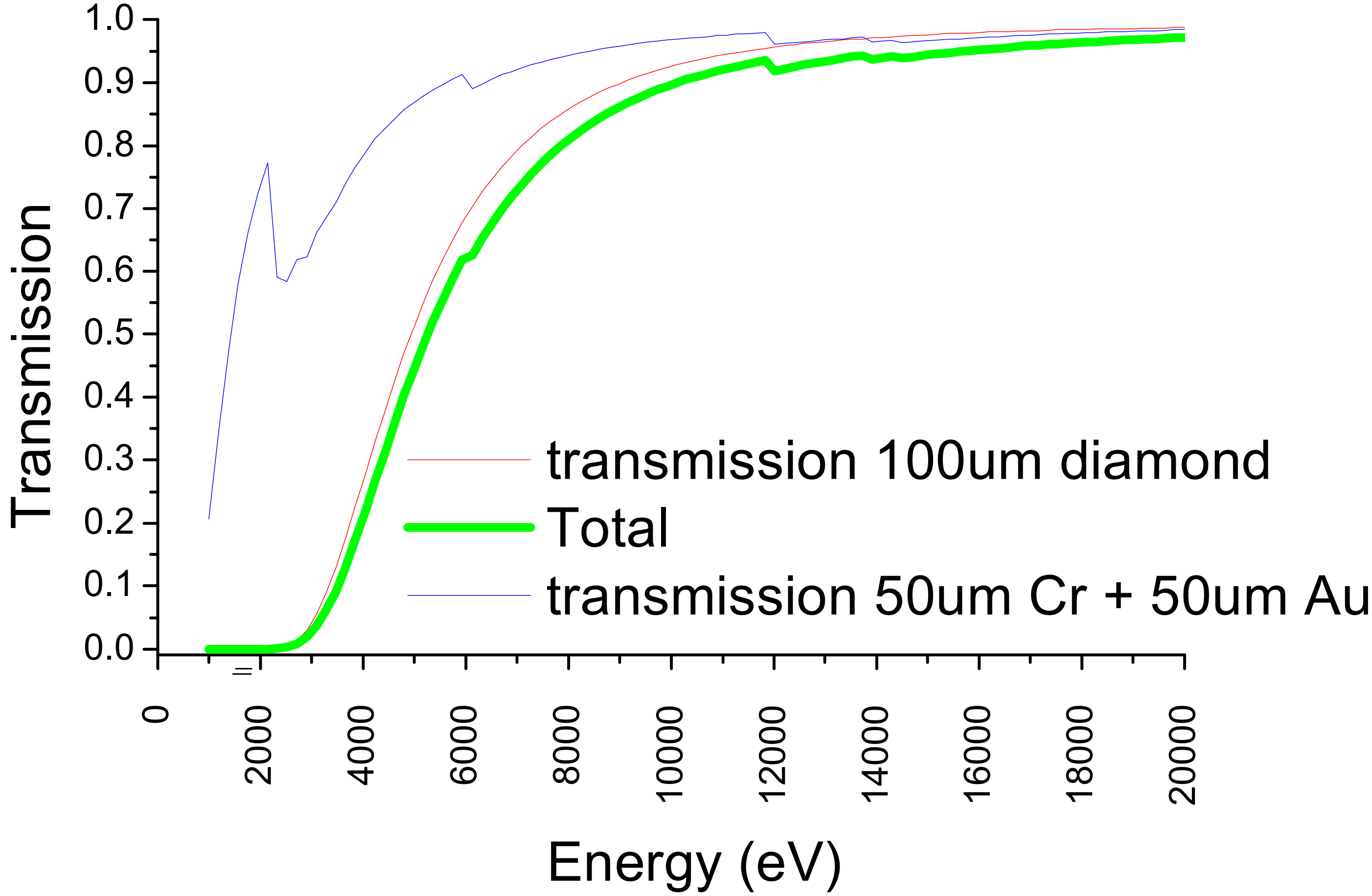
why *single crystal* material ?

no grain-boundary artifacts
(performance as monitor, beam coherence degradation)

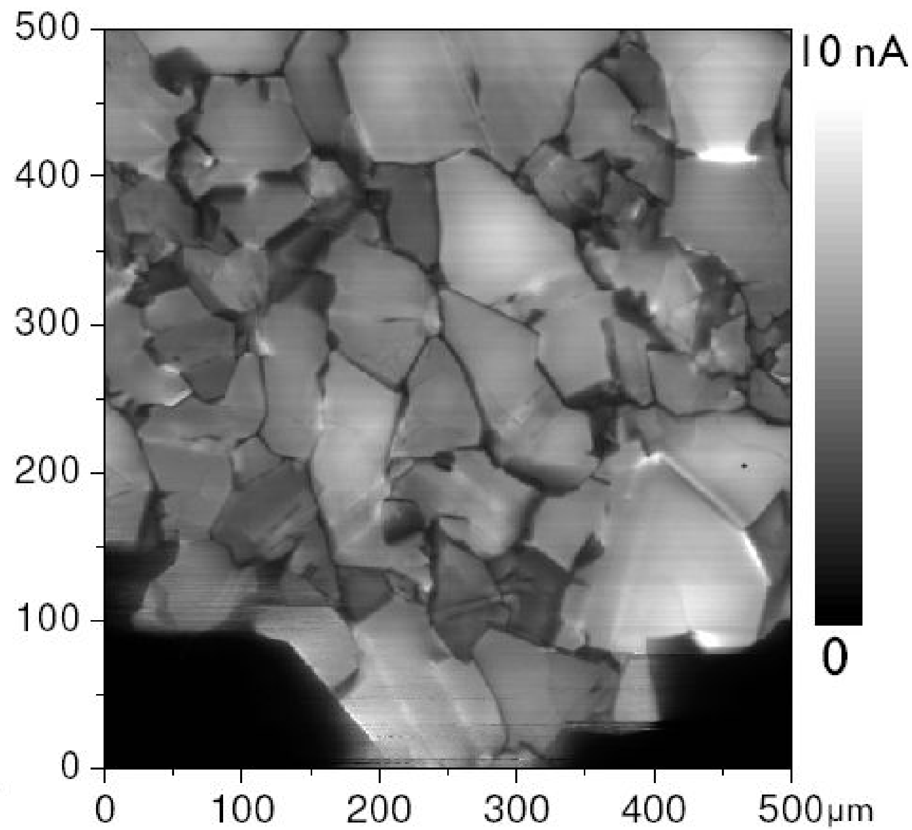
charge-carrier lifetime >50nsec
(-> charge signal collection over > mm distances)

Material absorption limitations

Diamond with metal contacts



Spatial response, polycrystalline film CVD diamond



courtesy Ph. Bergonzo, CEA

ESRF ID21 microscopy beamline

raster scan, ~1µm beam at 5keV

and ~10^9 photons/sec.

'contrast' in image is from
crystal grain boundaries
(trapping and oblique E fields)

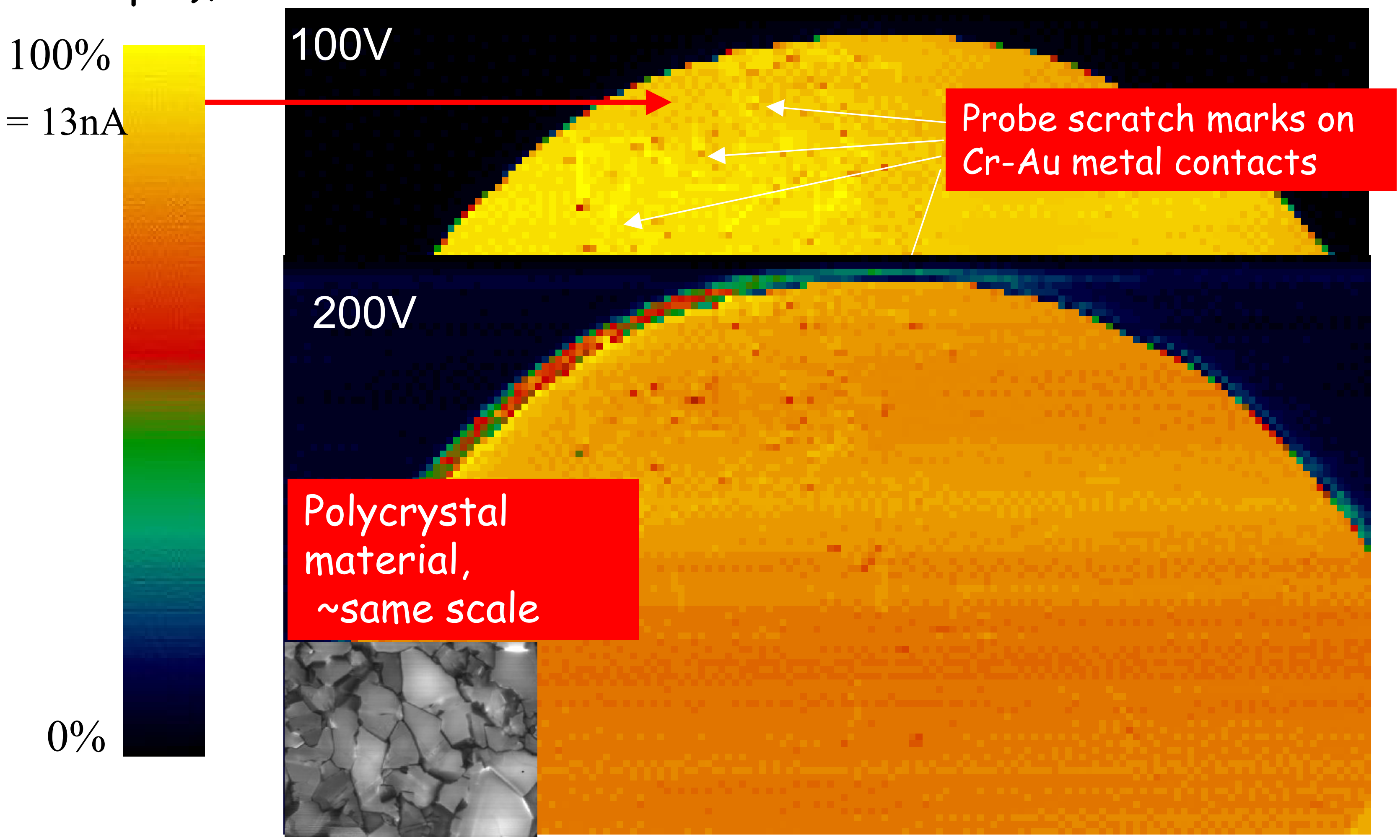
for beam monitoring?

beam width >100µm ~ OK

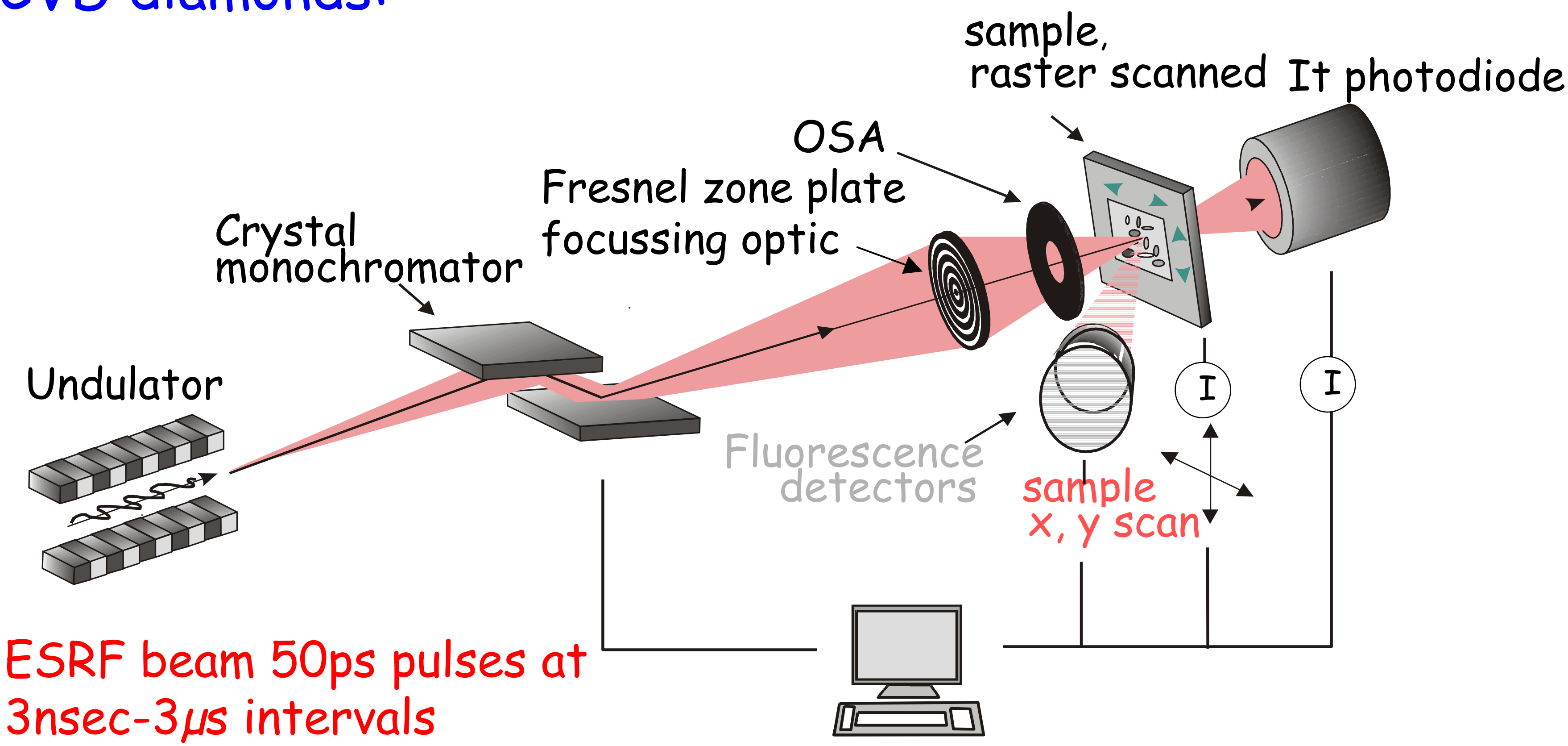
beam width <100µm ✗

Uniformity of *Single Crystal* CVD Material…

mapping at ID21, 20μm pitch raster scan, 0.1 sec/point current signal from 300μm thick diamond (Berdermann sample), annealed Cr/Au contacts



ID21 X-ray microscope scanning of contacted CVD diamonds:



ESRF beam 50ps pulses at 3nsec-3μs intervals

A Fresnel zone plate focuses the beam to a *sub-micron* probe. Unwanted diffraction orders from the zone plate are removed by a central stop and an order selecting aperture (OSA).

→ direct charge/current probe of detector (2 - 6keV)

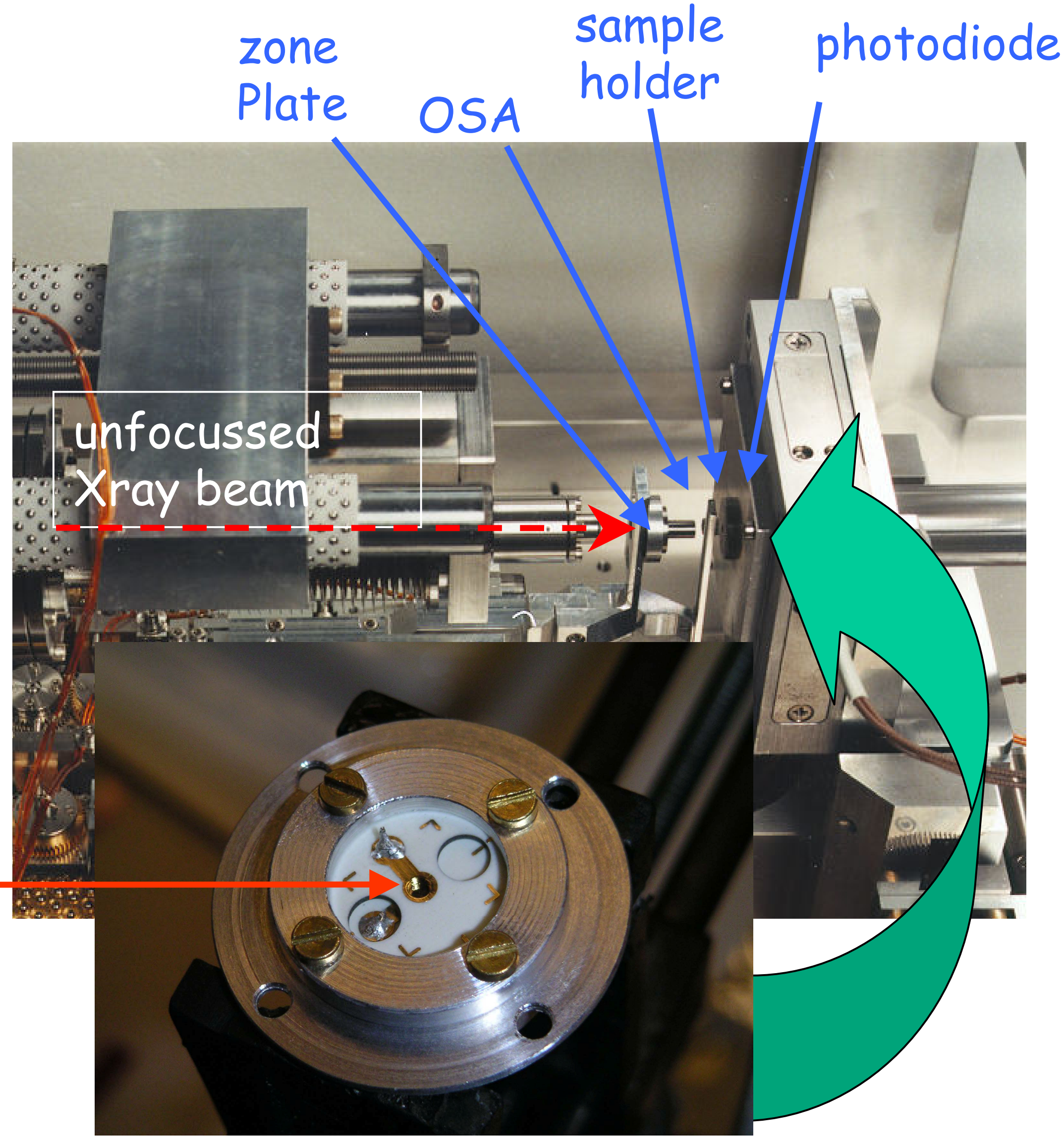
ESRF/ID21 X-ray microscope: tests with CVD *single crystals*

12 Oct 2004

$0.4 \times 0.9\ \mu m^2$ fwhm beam spot,

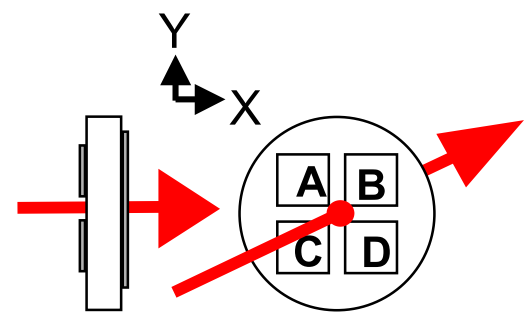
3×10^8 ph/sec @5keV

SC-CVD diamond
(Berdermann sample)
3mm square,
300mm thick
Cr-Au contacts
in Teflon PCB sandwich



CVD diamond beam monitors: basic principle

Beam intensity: use thin (~50μm at 10keV) crystal with Xray 'transparent' electrode contacts Ti, Mo, Al, … B?
Diamond bulk acts as an 'ionization chamber'

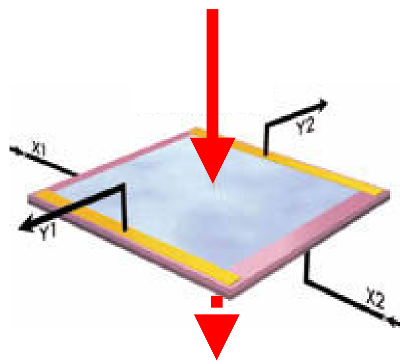


$$X = \frac{(A+C)-(B+D)}{A+B+C+D}$$
$$Y = \frac{(A+B)-(C+D)}{A+B+C+D}$$

Beam Position: e.g. quadrant motif

-> beam 'centre of gravity' by weighting four electrode currents A, B, C, D.

OR

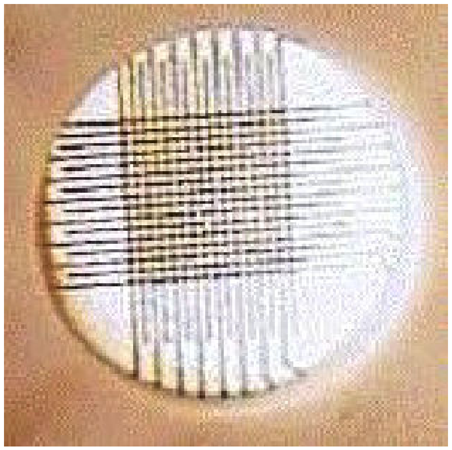


$$X = \frac{X1-X2}{X1+X2}$$
$$Y = \frac{Y1-Y2}{Y1+Y2}$$

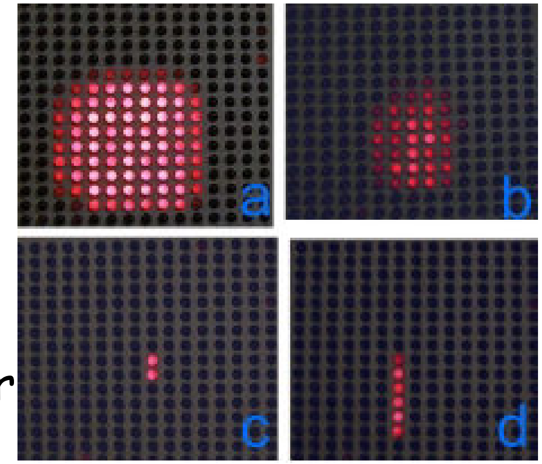
resistive surface contacts
-insensitive to beam size
-large linear spatial response

but this loses intrinsic ~nanosec time resolution (RC response limit)…

multiple electrode structures

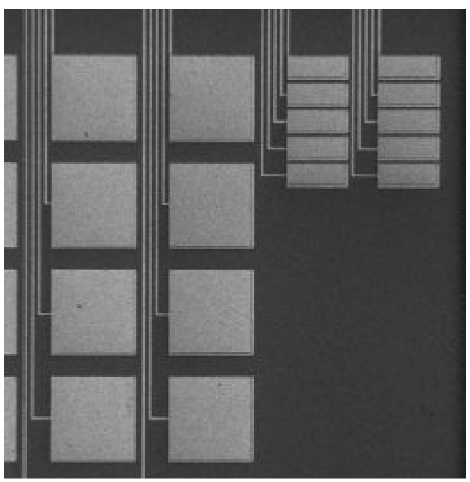


Two side 200nm *Al* strips on 175 μm *General* Electric *polyxtal'* diamond. Bias applied *sequentially* at 3kHz



Response to 'pink' *beam* undulator radiation after 13mm of *Al*

Deming Shu, et al., APS-Argonne Nat'l. Lab. Report (2000)



SLS-PSI PX beamline profile monitor. Test pixel structures on a *1.3 μm polyxtal* thick membrane, Ti/Al electrodes, Si_3N_4 isolation layer for tracks.

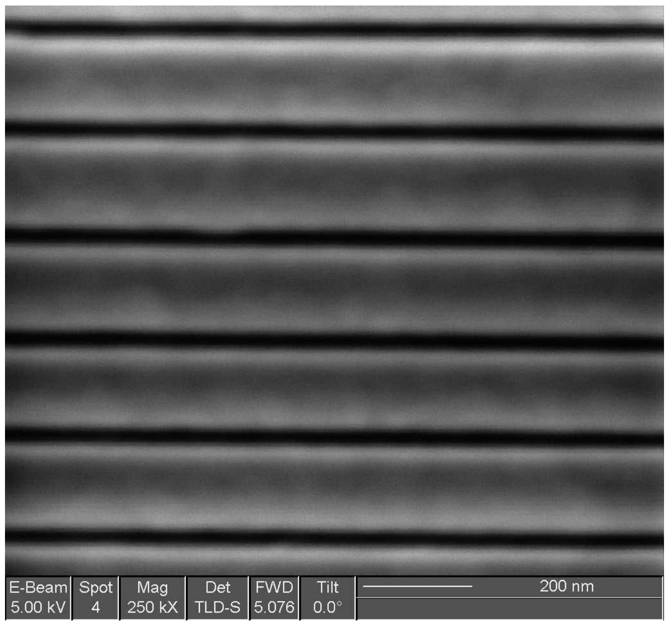
Smallest pixels 110 x 290μm^2

work continuing with EU FP6 BioxHit' funds*

**Automation for Protein Crystallography*

C. Schulze-Briese et al., NIM A 467-468 (2001) 230-234

Processing limits?



Courtesy Dan Pickard,
Stanford Nanofabrication Facility

Single crystal 18μm micron thick, 1mm diameter, natural Ib diamond

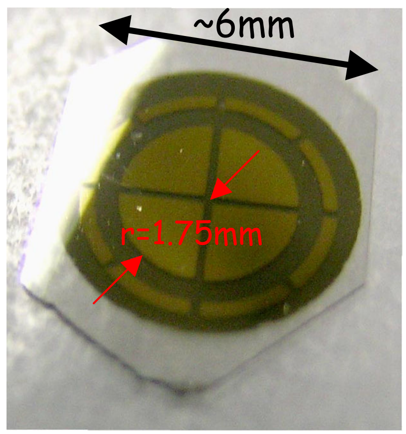
~30Å Mo + 3000Å Pt metal overlayer

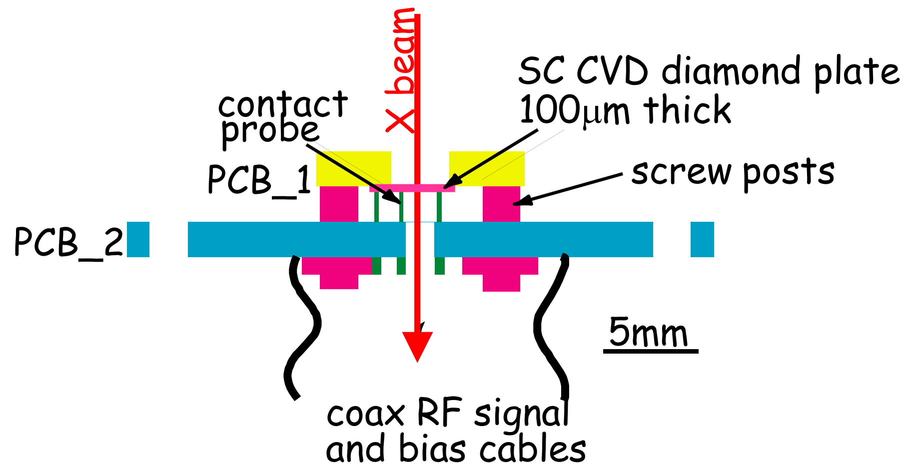
focussed (Gallium) ion beam etching of metal layer
30 *nanometer* trenches,
with 10:1 etch aspect ratio

!! 'physics' limits set by *photoelectron range* (~ few microns) and *charge diffusion* (~10 microns)

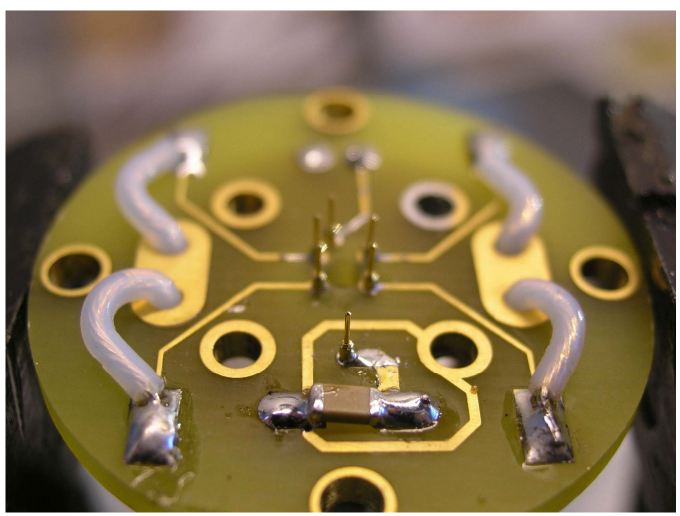
Diamond quadrant-BPM tests at ID21 (May 2005)

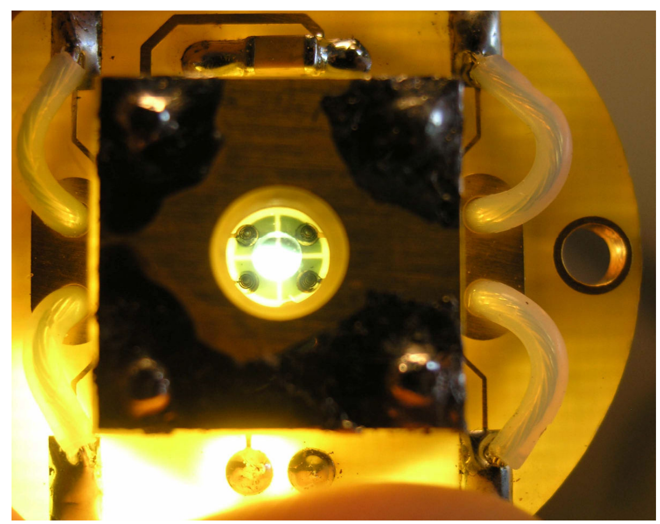
Plate thickness
100micron [E6]
2 x (20nm+20nm
Cr, Au contacts)
E6 sample, contacted
at GSI.





PCB assemby
with sprung
microprobes ,
'RF compatible'
layout





Uniformity of response

X-ray response (quadrant signal currents) as microbeam raster-mapped over surface

$1 \times 0.4\mu^2$, ~10^8 photos/sec at 7keV

Graphics removed, subject to NDA with Element Six

I-V curves, without beam (i.e. 'leakage current') and with beam on

Graphics removed, subject to NDA with Element Six

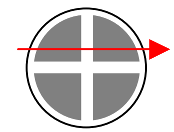
'Hot' defect, variation with bias

- High (~10x average) signal response defect, is turned on' as beam intercepts
- long (seconds) decay constant

Cause? Bulk, or contact electrode/ surface defect problem?

Graphics removed, subject to NDA with Element Six

Position response as a BPM



For small beam (< 30μm), convolution with charge collection diffusion, photoelctron range…) signal slope ~5% (80pA) /micron

For large beam (> 30μm), response is defined 'geometrically' simply as 'beam crossing a thin line'

signal slope ~0.5% (250pA) /micron

Graphics removed, subject to NDA with Element Six

Current signal linearity with X ray beam intensity

Linear over > 3 orders (measured with Si diode normalization)

Maximum 'diffusion' current density' measured ~1 mA/cm^2 dc equivalent (>0.1 A/cm^2 peak for ~2ns charge collection pulse width)

Graphics removed, subject to NDA with Element Six

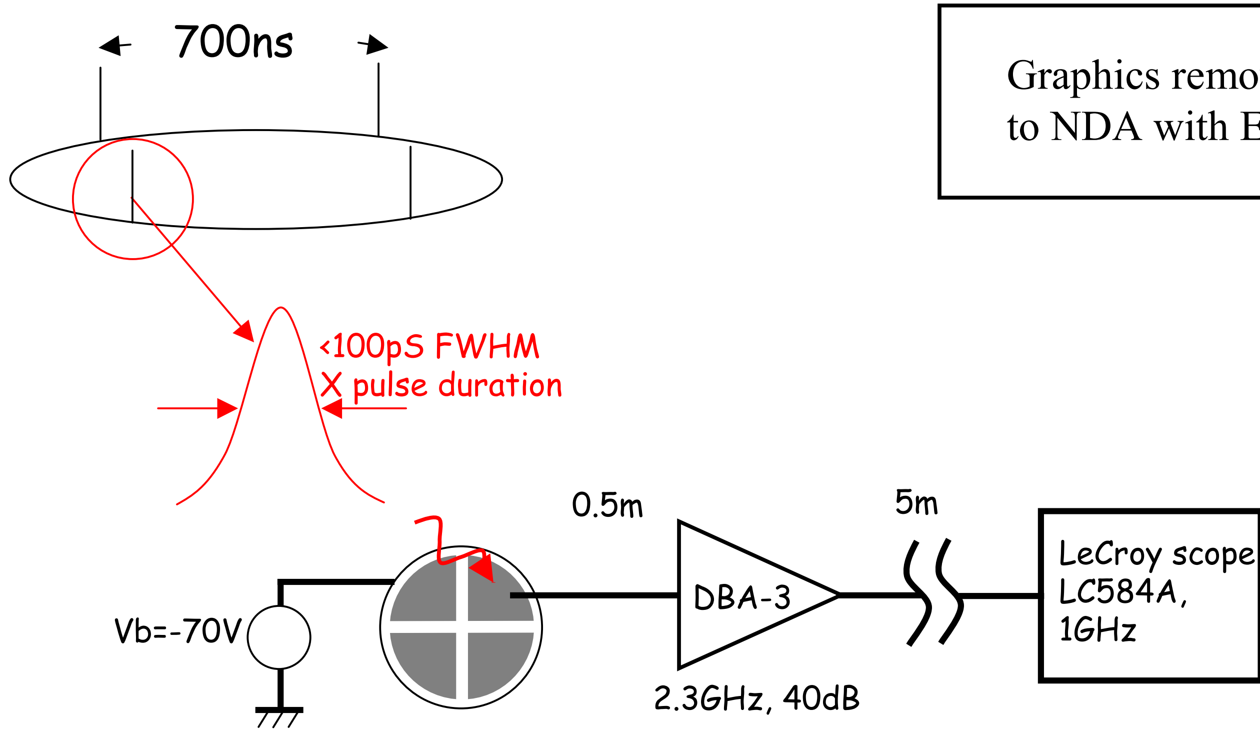
Signal from individual X-ray bunch

ESRF synchrotron in
4 bunch mode

Diamond plate 100μm thick,

0.7 $V\mu^{-1}$

Graphics removed, subject to NDA with Element Six



Individual signal pulses correspond to ~160 X-rays @7.2keV,absorbed in diamond plate, i.e.total signal pulse energy ~1MeV)

Signal pulse shape: effect of bias and beam position

200µm beam centered on the upper left electrode:

Pulse shape full width is 'consistent' with 60(45)µm/ns @ 0.5Vµm hole(electron) drift velocities*

'Split signal' (beam centered in quadrant isolation gap:

signal shape ~same, with amplitude (measured on one quadrant) simply halved.

*Pernegger et al, J. Appl. Phys. 97, 073704 (2005)

Graphics removed, subject to NDA with Element Six

Radiation aging question

~100's of Gigarad

(ID21 microfocussed beam ~1µm, overnight test)

→Apparent ~0.5% *increase* in sensitivity

→data considered inconclusive, more data analysis and repeat, long term beam tests needed.

Graphics removed, subject to NDA with Element Six

Summary: remaining Critical issues

- thinning and surface preparation
- reliable/reproducible contact technologies
  (low resistance, high drift field with low reverse current)
- device lithography, mounting- and handling- problems
  for small & thin & (<5mm size, ~50um thick) devices
- thermal bonding issues for white beam (power!) application