Stacking fault density and local interface composition in II-VI / III-V heterostructures

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- Quantum Devices Division

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  Division Leader: F. Beltram (Pisa)

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  ABS, LEED, UPS
  Division Leader: F. Tommasini (Trieste)

- Analytical Division

  AES, XPS, UPS, LEED, EELS
  Division Leader: M. Sancrotti (Milan)

- SR activity (Surface Diffraction beamline)

TASC activities:

Device fabrication and characterization:

(Prof. Beltram, SNS, Pisa, Italy)

HBTs
MESFETs
MQW detector
Optical cavities
Superconductor-semiconductor devices

Basic materials research:

(Prof. Franciosi, TASC-INFM, Trieste)

Heteroepitaxy
Band offset measurements
Schottky barrier height determination

Blue and blue-green Lasers

Methods and collaborations:

Solid Source MBE chambers for III-V and II-VI growth

In situ monochromatic XPS

Hall effect measurements

PL, PLE and absorption optical characterization

I-V transport measurements

Photolitographic device processing

TEM characterization (Ganière, EPFL, Lausanne)

XRD analysis (Tapfer, CNRSM, Brindisi, Italy and Bauer, Linz, Austria))

Microgun-pumped laser fabrication (Molva, LETI, France)

RBS measurements (Drigo, University of Padova, Italy)

Time resolved PL optical measurements (Cingolani, University of Lecce, Italy)

Photoemission Spectroscopy with Synchrotron Radiation (University of Minnesota, USA)

Motivation:

II-VI / III-V heterojunctions are crucial elements of most II-VI blue-green lasers

Native stacking faults control laser degradation

Prototypic systems:

Pseudomorphic ZnSe/GaAs(001) heterostructures

Lattice-matched ZnSe/$In_{0.04}Ga_{0.96}As$ heterostructures

BPR - technique:

Zn/Se flux ratio (BPR) -> interface composition

low BPR -> Se-rich interface

high BPR -> Zn-rich interface

Local interface composition -> band offsets

(Nicolini et al., Phys. Rev. Lett. 72 (1994) 294)

Structural properties of engineered interfaces

(Heun et al, Appl. Phys. Lett. 70 (1997) 237)

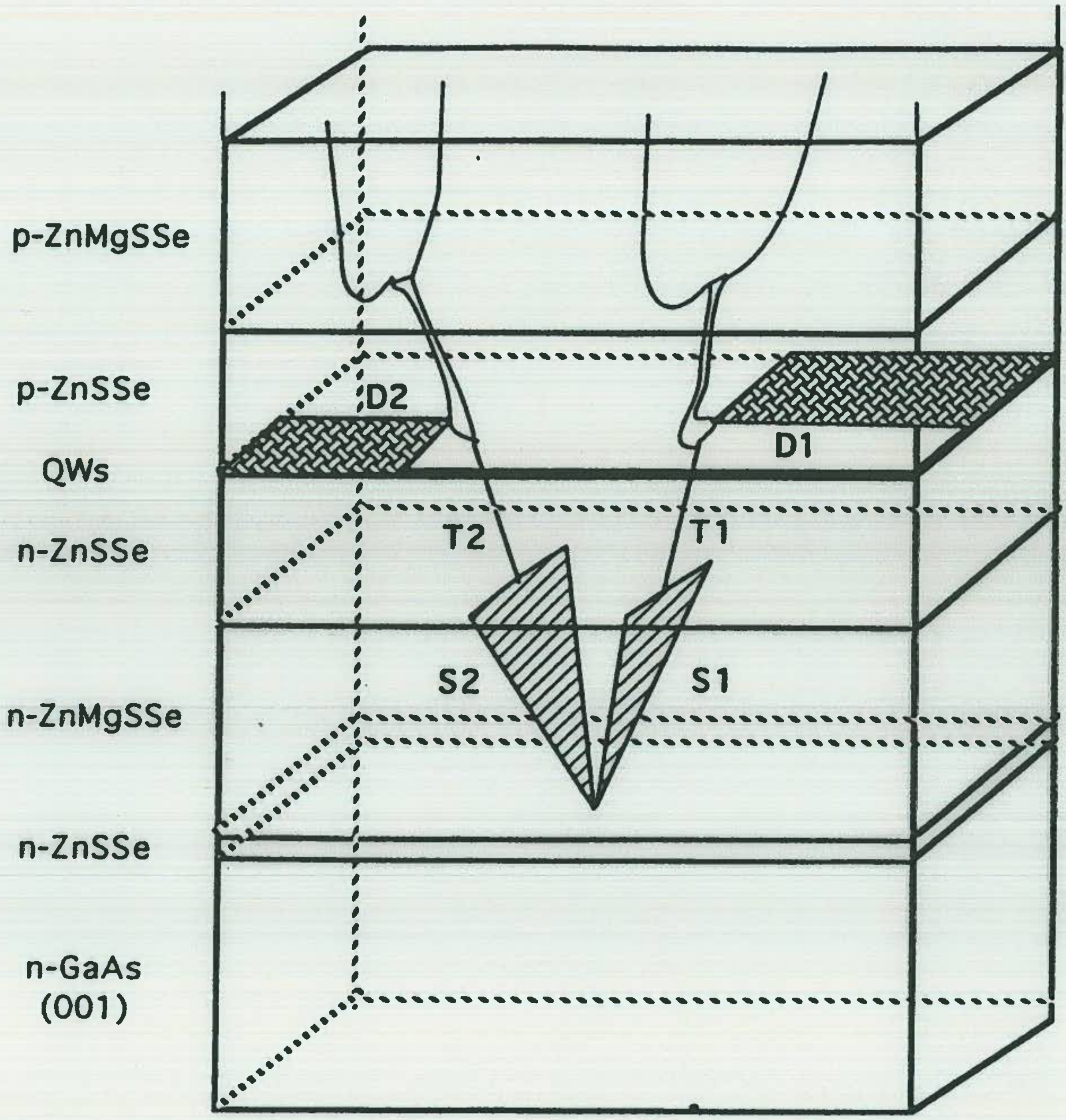
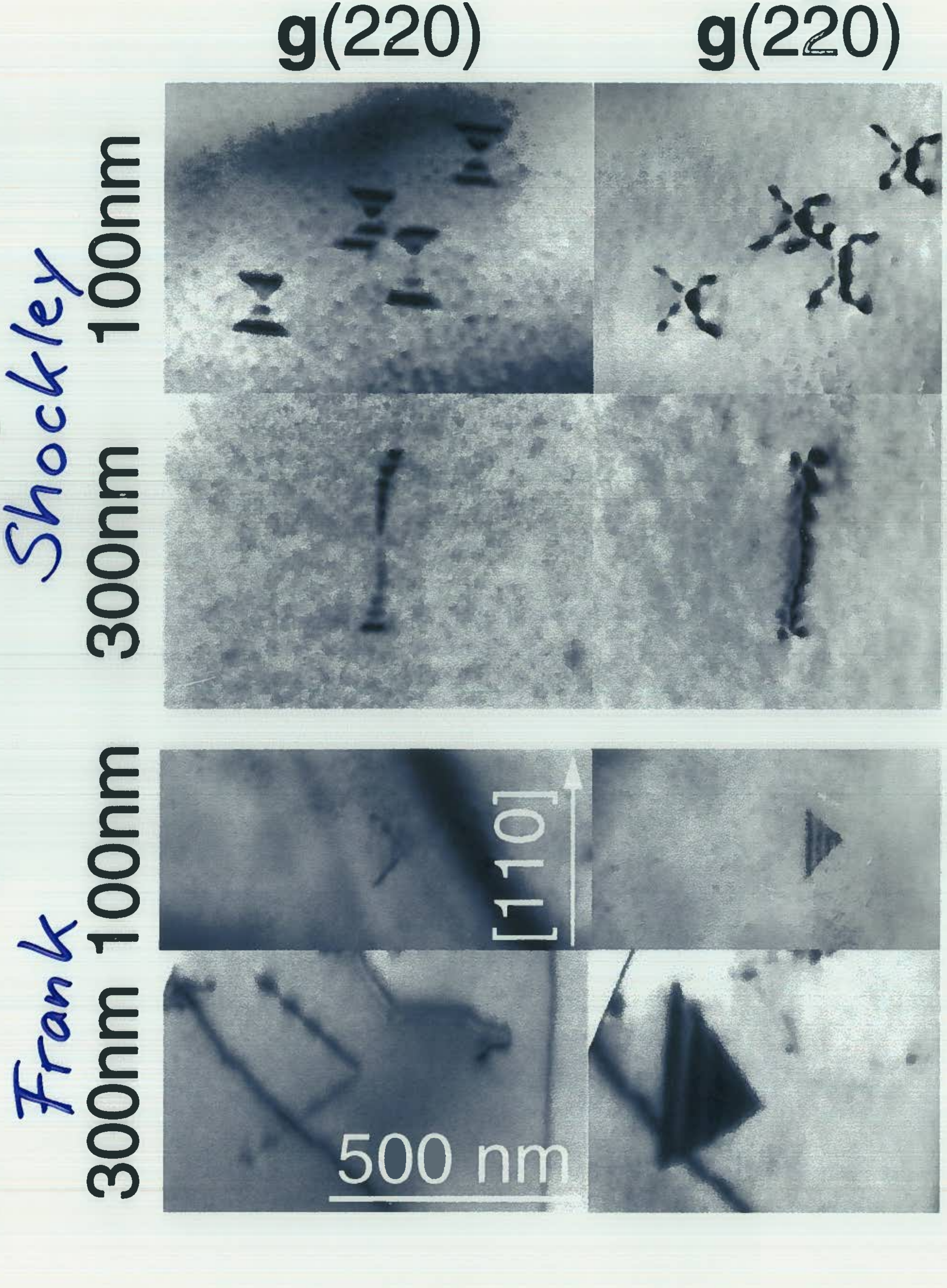
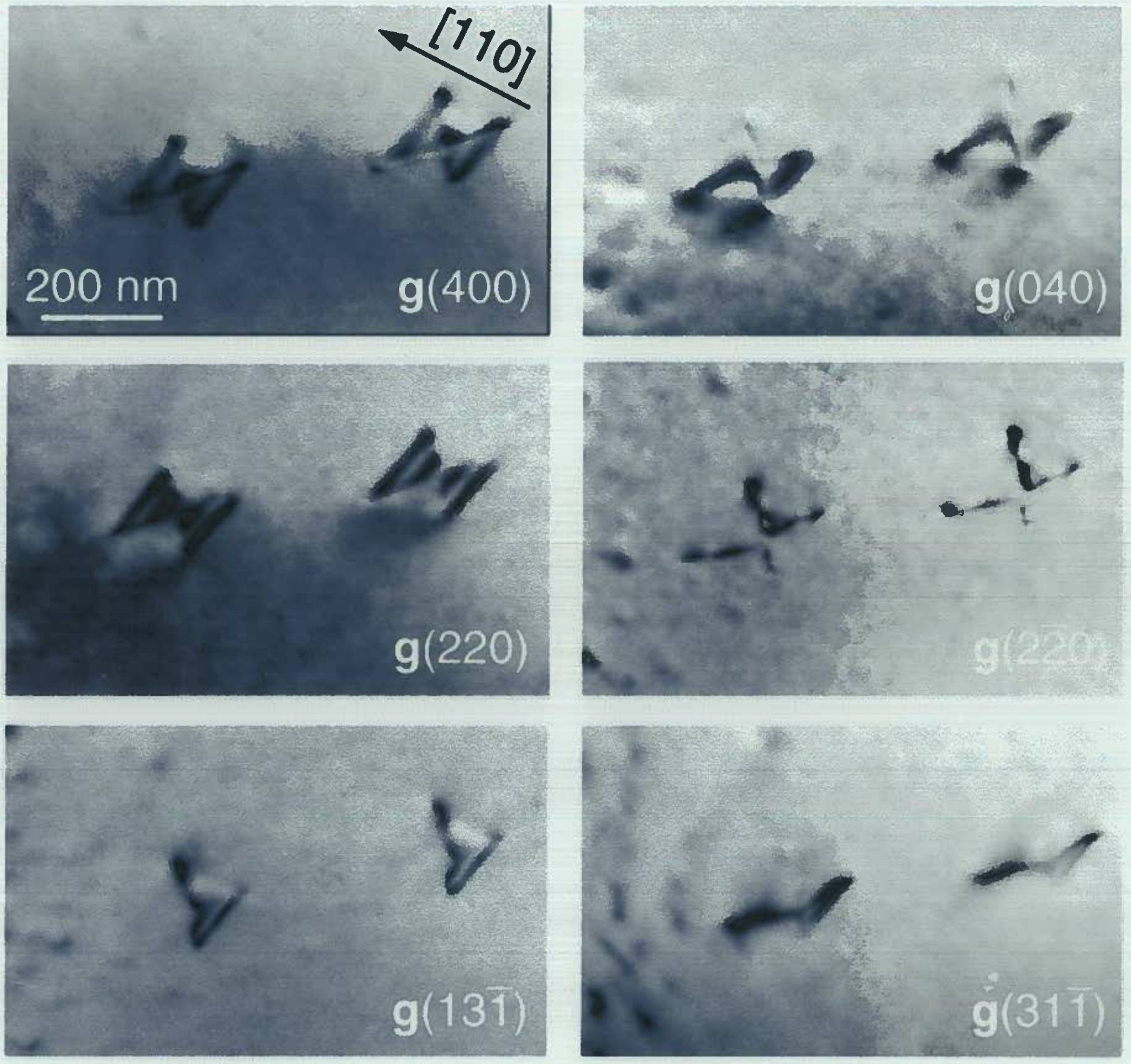


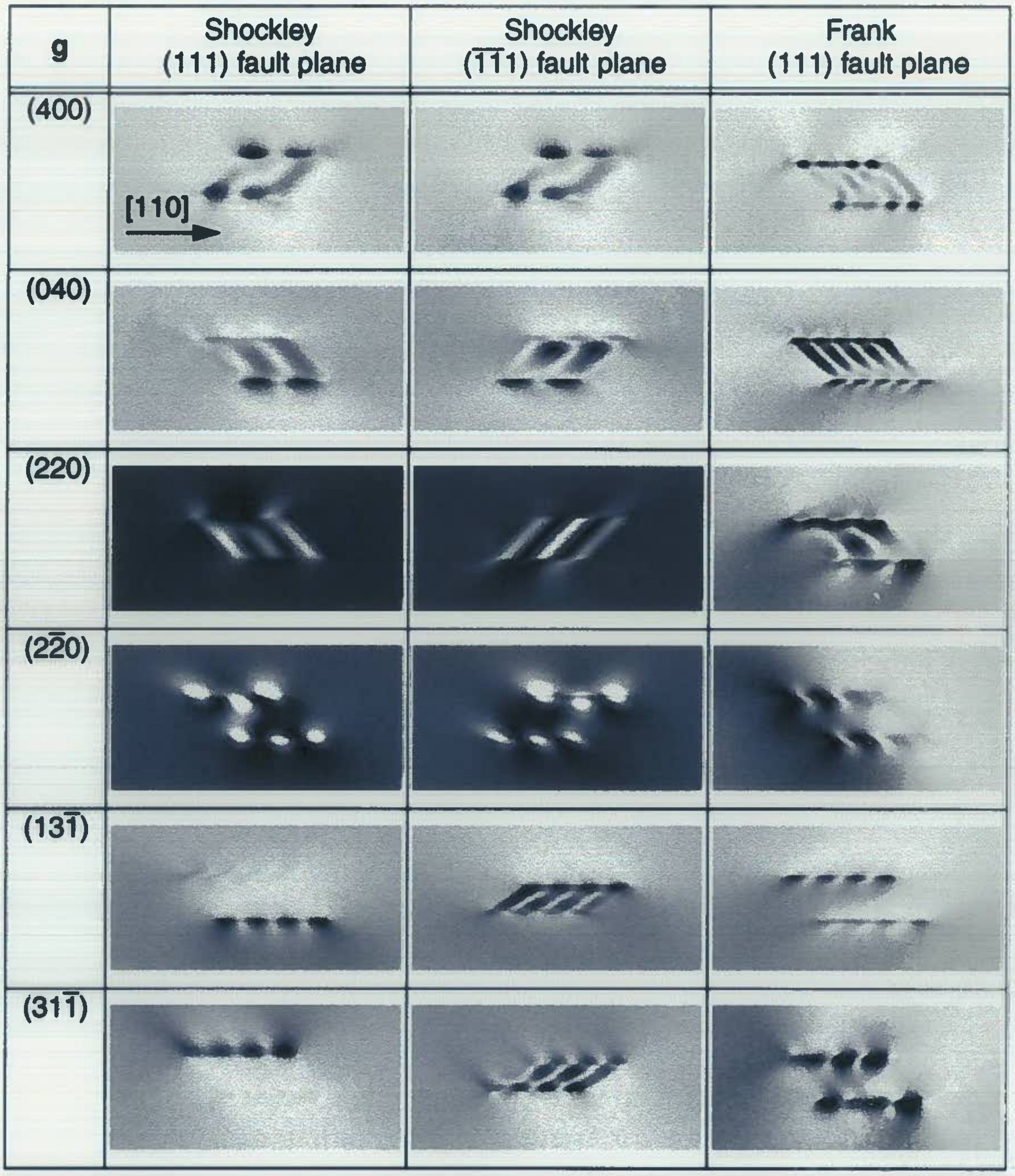
FIG. 3. Schematic showing the three dimensional arrangement of the defects shown in Fig. 2.

Hua et al.: APL 65 (1994) 1331

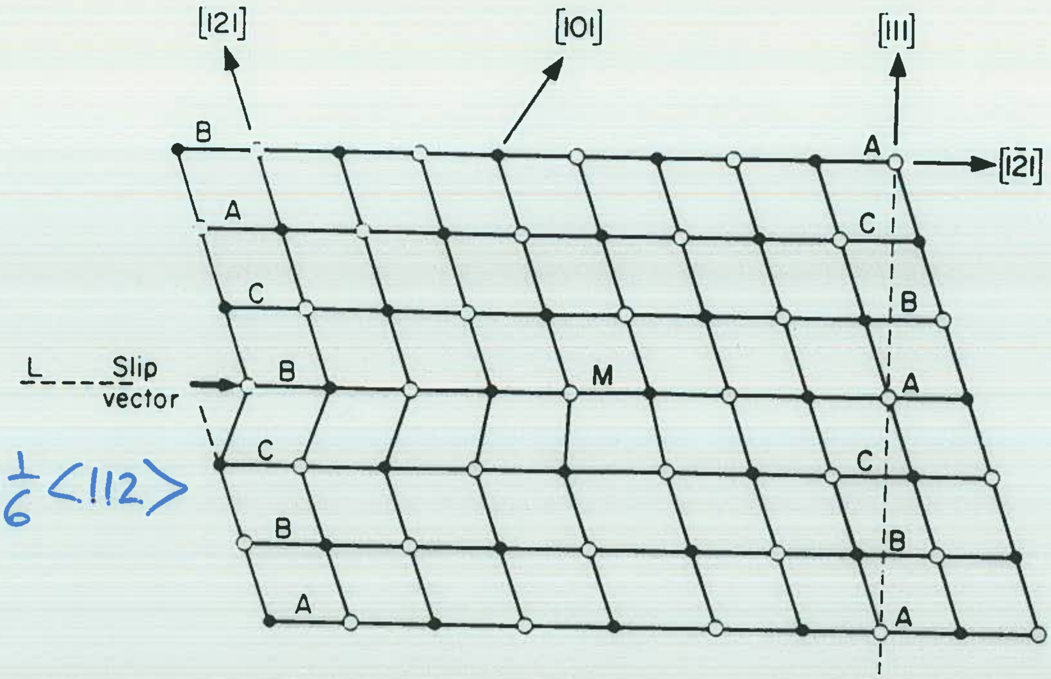

g(220)
g(2$\bar{2}$0)
Shockley
100nm
300nm
Frank
100nm
300nm
[110]
500 nm



Identification of Shockley stacking faults, using different reflections.

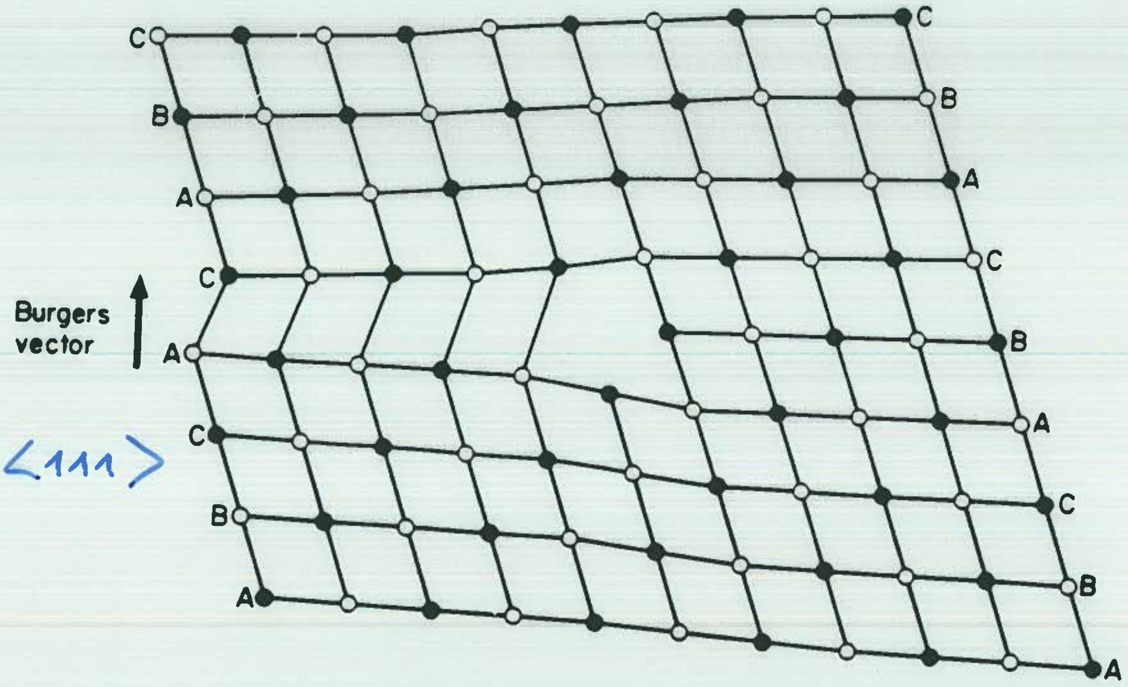


Simulated images for different faults



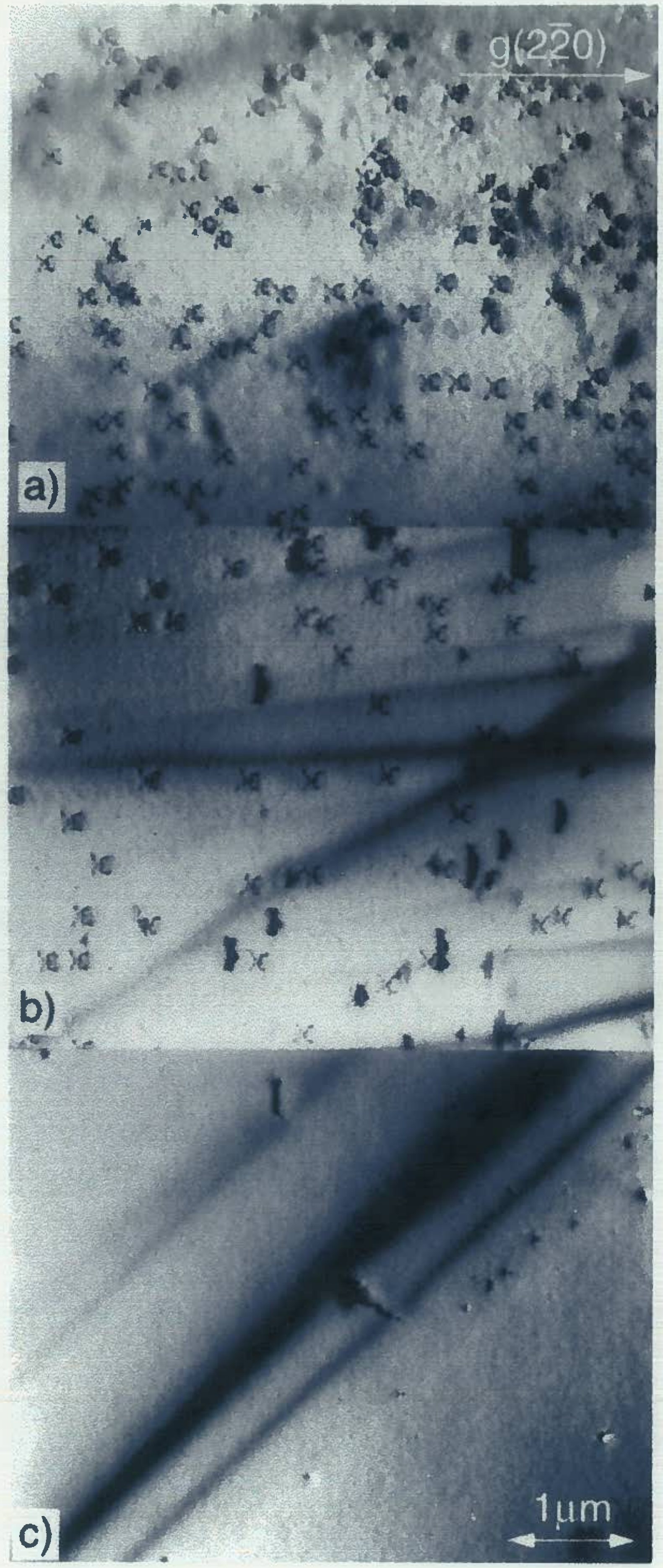
$\vec{b} = \frac{1}{6}\langle 112 \rangle$

FIG. 5.2. Formation of a $\frac{1}{6}[1\bar{2}1]$ Shockley partial dislocation at M due to slip along *LM*. The open circles represent the positions of atoms in the $(10\bar{1})$ plane of the diagram and the closed circles the positions of the atoms in the $(10\bar{1})$ planes immediately above and below the plane of the diagram. (From Read (1953), *Dislocations in Crystals*, McGraw-Hill.)



$\vec{b} = \frac{1}{3}\langle 111 \rangle$

FIG. 5.11. Formation of a $\frac{1}{3}\langle 111 \rangle$ Frank partial dislocation by removal of a close-packed layer of atoms. (From Read (1953), *Dislocation in Crystals*, McGraw-Hill.)



BPR = 10

7×10^8 cm^{-2}

BPR = 1

2×10^8 cm^{-2}

BPR = 0.1

1×10^5 cm^{-2}

100 nm ZnSe / GaAs (001)

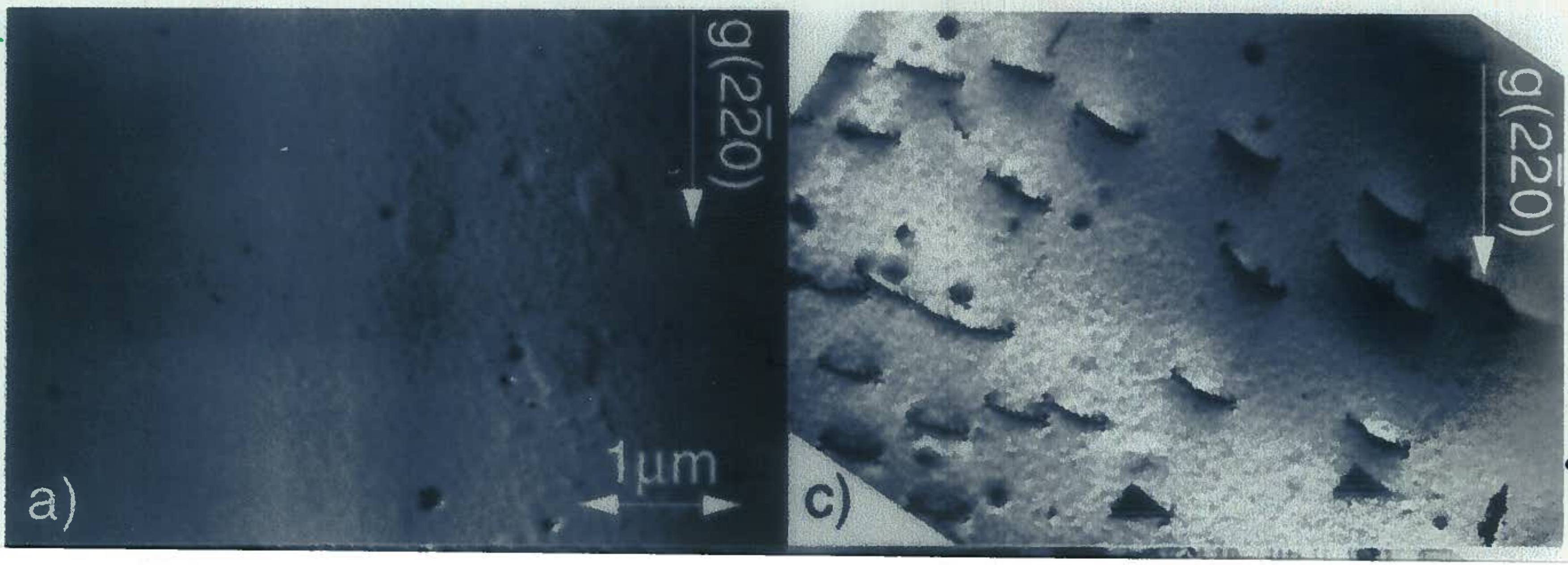
Heun et al.: JVST (submitted)

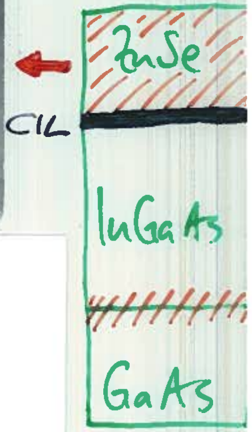
BPR = 0.1

BPR = 10

$2\times10^5\ cm^{-2}$

$1.6\times10^8\ cm^{-}$

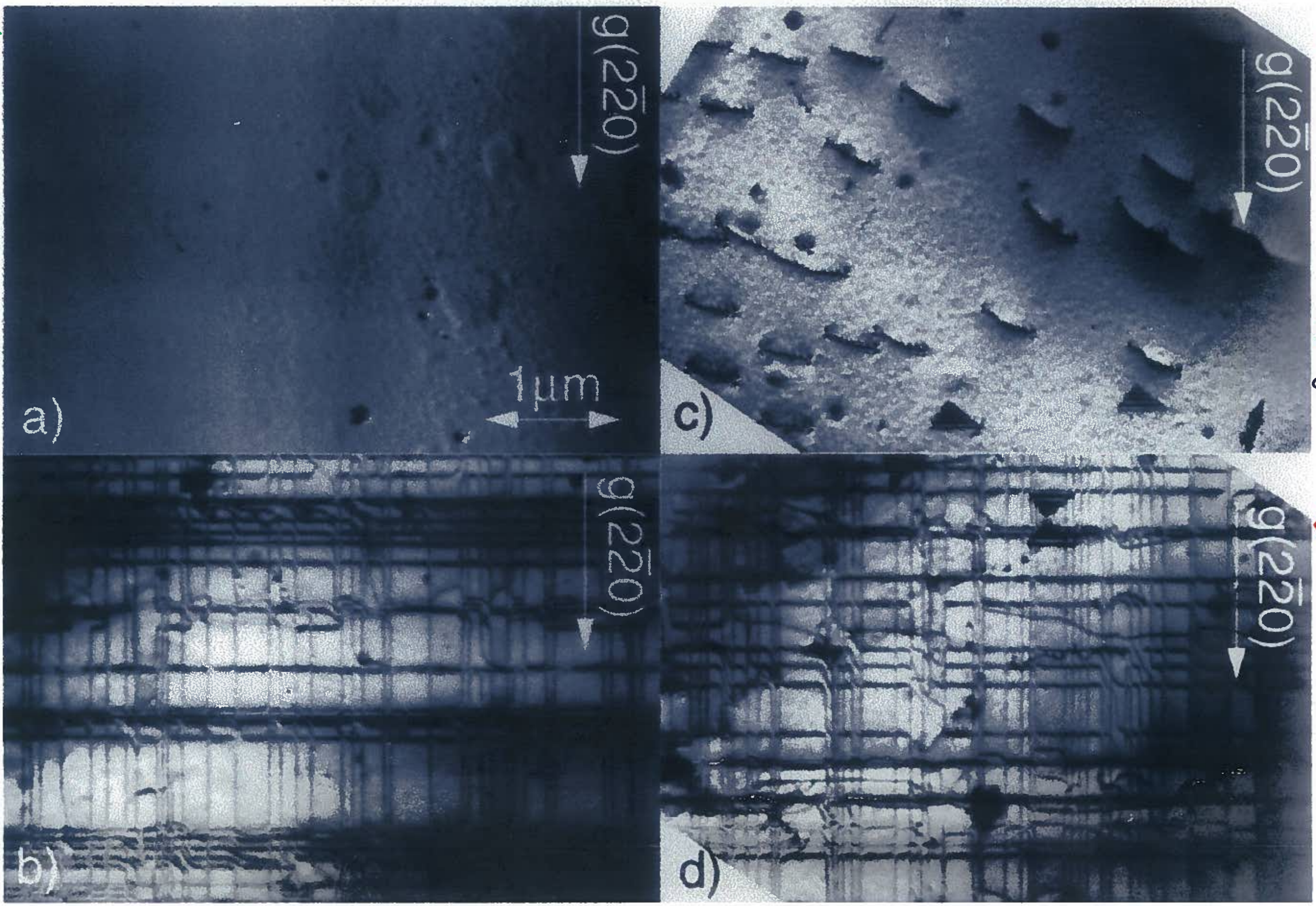




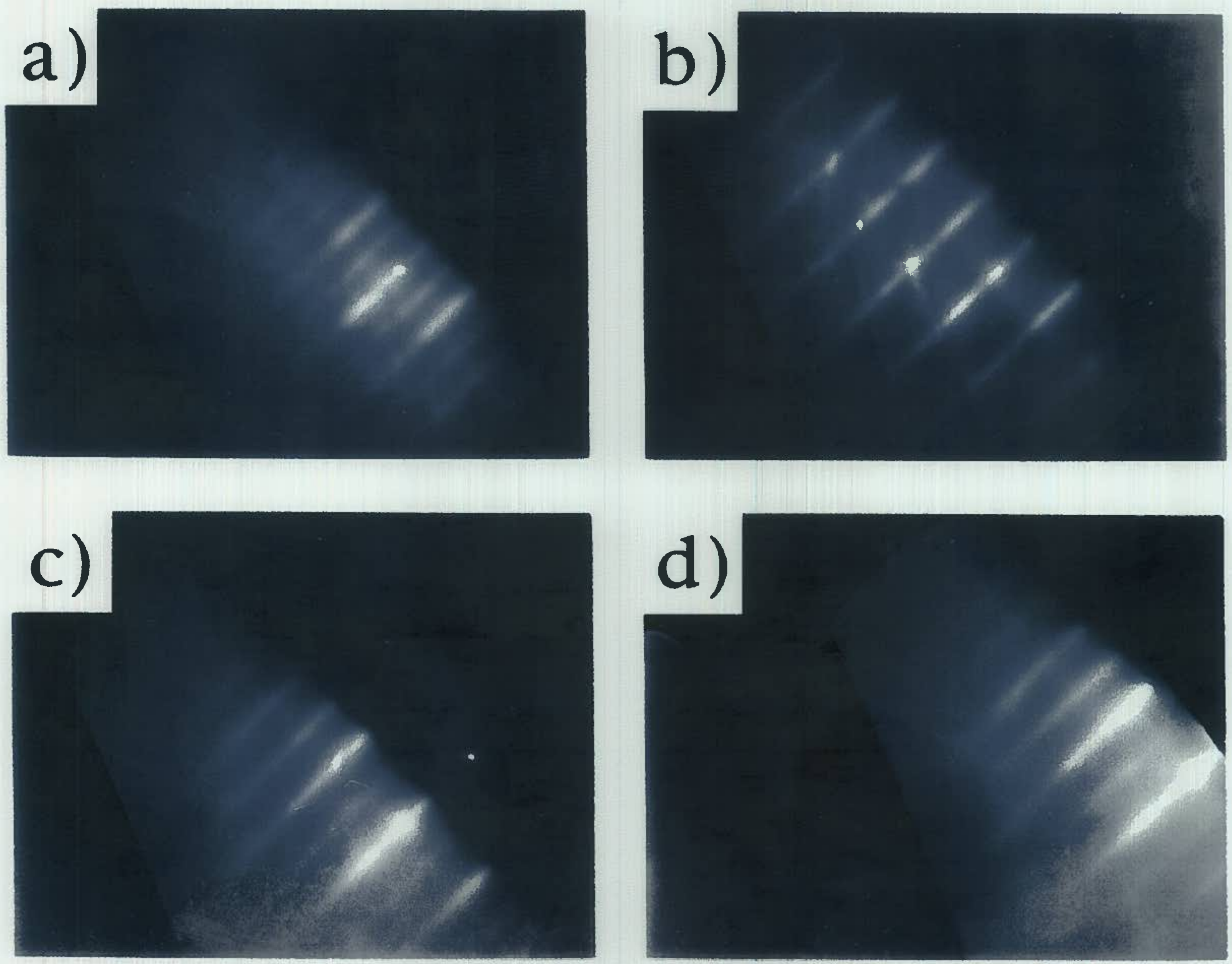
Heum et al.: JVST (submitted)

BPR = 0.1 BPR = 10

$:2\times10^{5}\ \mathrm{cm}^{-2}$ $1.6\times10^{8}\ \mathrm{cm}^{-}$



300nm ZnSe / $In_{0.04}Ga_{0.96}As$ / GaAs (001)



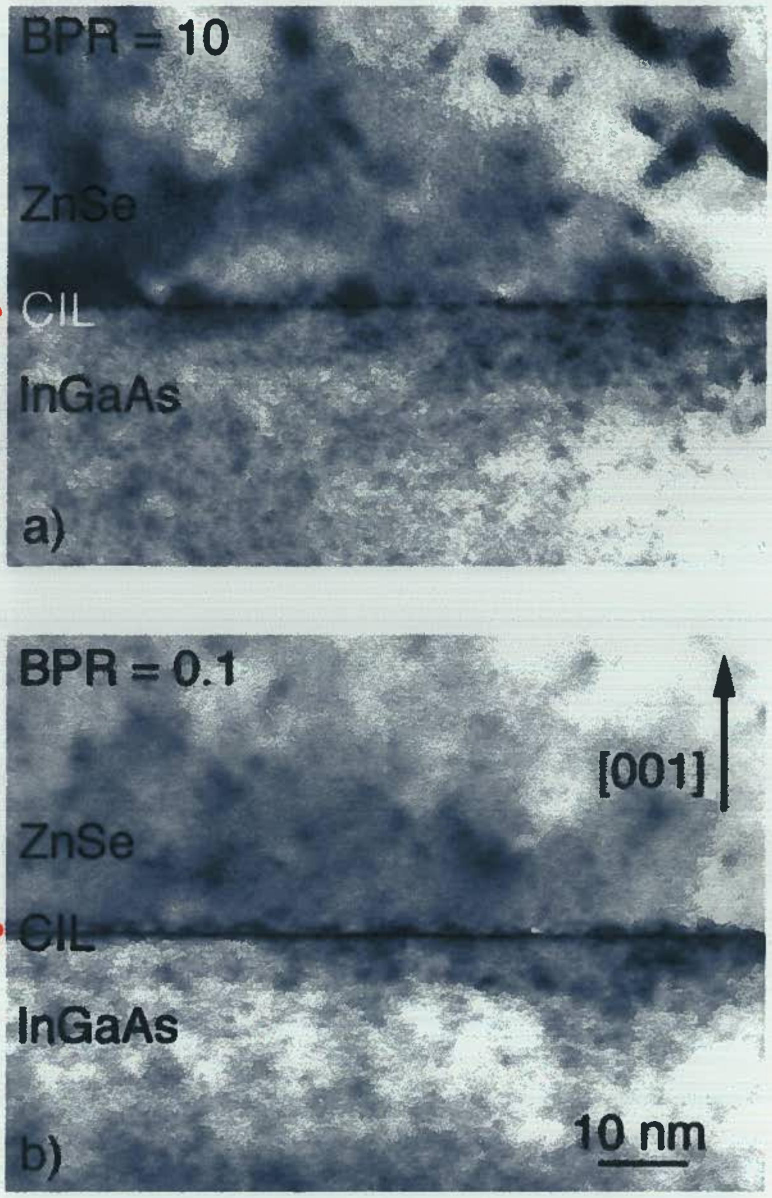
BPR=0.1

2x1

BPR=10

c(2x2)

2 nm ZnSe CIL / GaAs (001)



BPR = 10

dark dotted line

? Ga_2Se_3 ZnAs

BPR = 0.1

continuous line

Results:

Shockley stacking fault (SF) pairs most common defects

Se-rich interfaces yield 3-4 orders of magnitude lower densities of Shockley SF pairs than Zn-rich interfaces

Isolated Frank SF also affected but to a lesser extent

Interface composition controls the stacking fault density

Same results for ZnSe/GaAs and ZnSe/$In_{0.04}Ga_{0.96}As$

Strain plays no major role

2D growth for both Se-rich and Zn-rich interfaces

Lateral inhomogeneities for Zn-rich interfaces

Se / Zn-predosing:

Se: high density of stacking faults (10^8 cm^{-2})
3D growth

Zn: low density of stacking faults ($< 5 \times 10^4$ cm^{-2})
2D growth

(Kuo et al., SPIE 2228 (1994) 144)

CIL and predosing are not equivalent in regard to the structural quality of engineered structures