The epitaxy of Alkaline Earth Fluorides on Semiconductors

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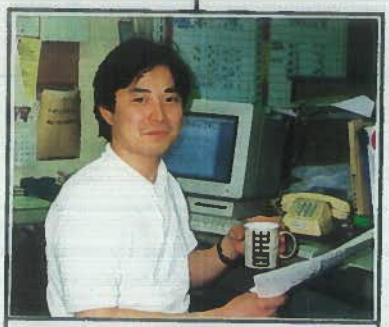
放射光応用研究グループ（機放G）
Synchrotron Radiation Research Group

Dr. M. Oshima

軟X線サブG(EXAFS, XSW)

Mr. S. Maeyama



Mr. M. Sugiyama

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Dr. Y. Watanabe

Mr. F. Maeda

Mr. T. Kiyokura

NTT R&D, WHICH LEAD UP TO THE BEST SERVICE

Research and Development Headquarters

■ **Engineering Planning Department**

■ **Research and Development Management Department**

Network Systems Development Department

Development of access and network systems

Telecommunication Network Laboratory Group

Planning for research and development of access and network systems

■ **Telecommunication Networks Laboratories**
Planning for basic telecommunications network architecture, and research and development of systems related to the telecommunications network innovation

■ **Access Network Systems Laboratories**
Research and development of optical access facilities and their construction and maintenance technologies

■ **Network Service Systems Laboratories**
Research and development of switching functions and systems to enhance the sophistication and economical features of telecommunications networks

■ **Optical Network Systems Laboratories**
Research and development of functions and systems to implement sophisticated and economical cable transmission systems for telecommunications networks

■ **Wireless Systems Laboratories**
Research and development of functions and systems to implement sophisticated and economic wireless transmission systems for telecommunications networks

Multimedia System Laboratory Group

Planning for research and development of multimedia and other user systems

■ **Information and Communication Systems Laboratories**
Research and development of databases, protocol processing, and sevices and operations based on AI technology

■ **Human Interface Laboratories**
Research and development for economical implementation of natural and efficient user-friendly technologies and related systems

■ **Software Laboratories**
Research of software's substance, and efficiency enhancement and systematization of software development

Science and Core Technology Laboratory Group

Planning for basic technological research and development of parts and materials relating to telecommunications

■ **LSI Laboratories**
Research and development of technologies that integrates element functions into custom LSIs for telecommunications systems

■ **Opto-electronics Laboratories**
Research and development of optical IC and part technologies to implement optical telecommunications systems

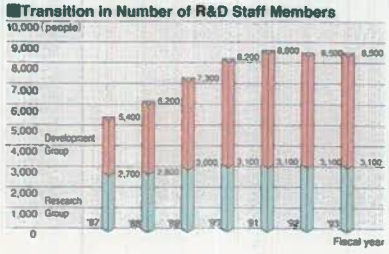
■ **Interdisciplinary Research Laboratories**
Research and development of innovative equipment and the related part and material tchnologies in the telecommunications field

■ **Communication Science Laboratories**
Basic research in information science

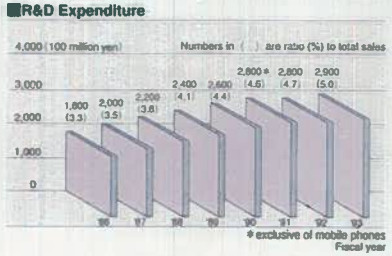
■ **Basic Research Laboratories**
Creation of new knowledge and concepts in the telecommunications field

R&D DATA

■Transition in Number of R&D Staff Members



■R&D Expenditure




Musashino R&D Center


Shinagawa Twins


Yokosuka R&D Center


Kyoto (in ATR)


Atsugi R&D Center


Tsukuba R&D Center


Ibaragi R&D Center


Makuhari Bldg.

Service Marketing and Support Headquarters

■ **Maintenance Service Planning Department Technical Assistance and Support Center**
Development of maintenance and support tools for technicians on the front lines

■ **Customer Equipment Department**
Development of ISDN-related communication equipment, business phones, and phones for home use

Business Communications Headquarters

■ **Network Services Department**
Development relating to telephone network services, leased line services and ISDN services

■ **System Services Department**
Development of large-scale integrated telecommunications systems

Service Engineering Headquarters

■ **Customer Systems Development Department**
Development of user systems to provide dieversified services including multimedia, high-speed computer and personal communications

■ **Telecommunications Software Headquarters**
Development of switching software to implement new services and operation systems to enhance maintenance and operational efficiency of telecommunications facilities

■ **Information Systems Headquarters**
Development of information systems, primarily software used in NTT

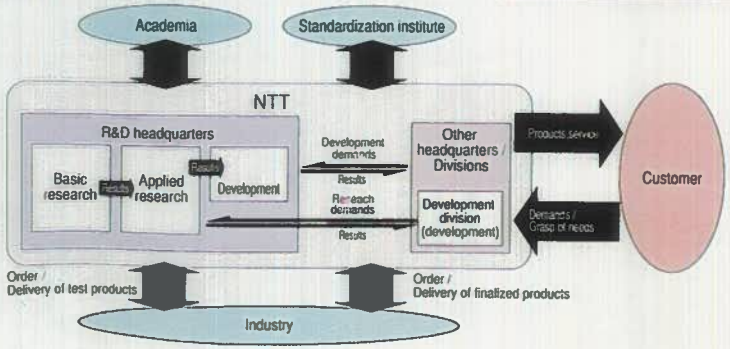
Packet Network Sector

Development of packet switching services for data transmission and total operation systems for packet networks

Visual Communications Sector

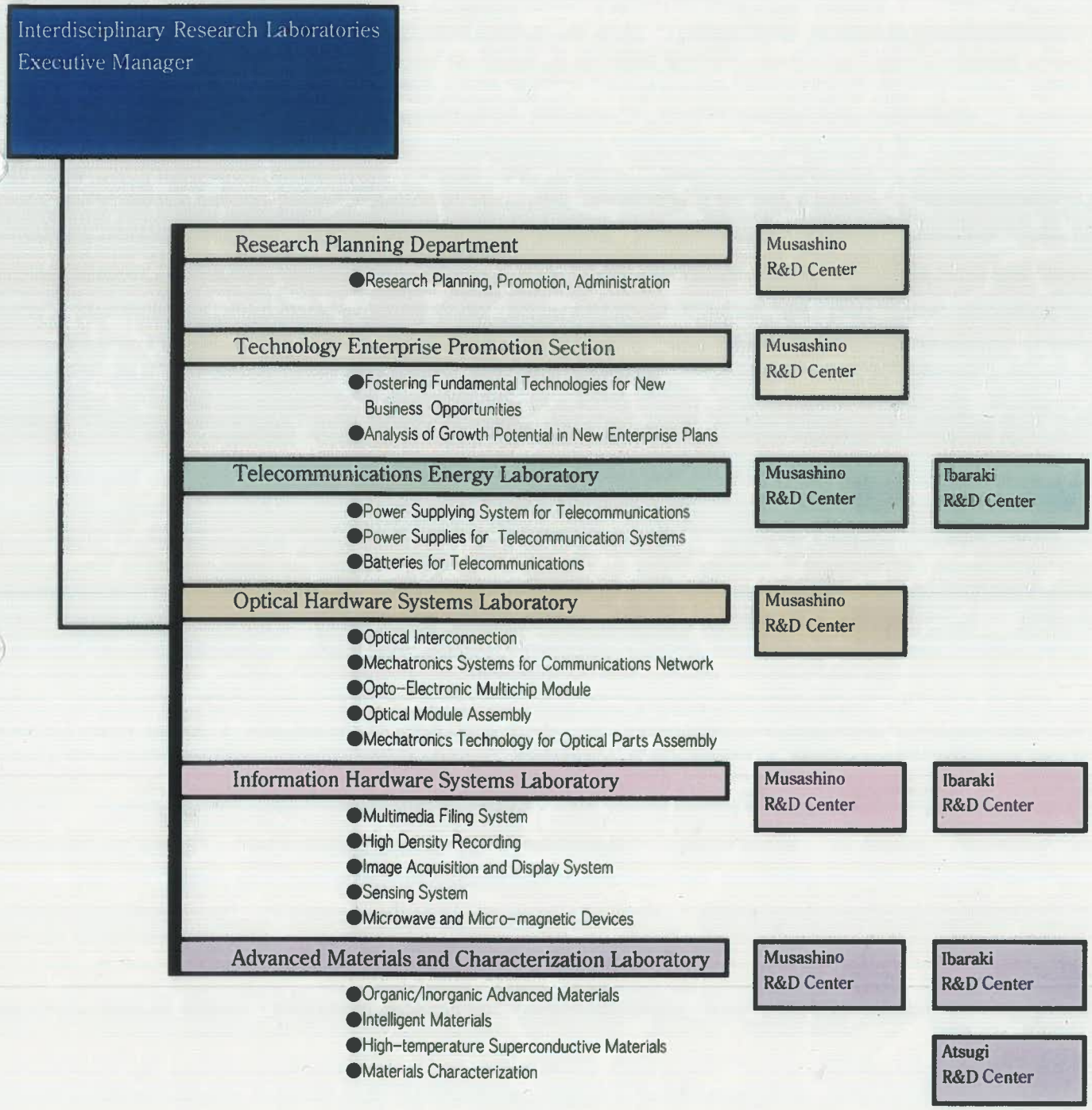
Development of facsimile and video communication services, including videotex and teleconferencing

■Flow from R&D to Service Operation



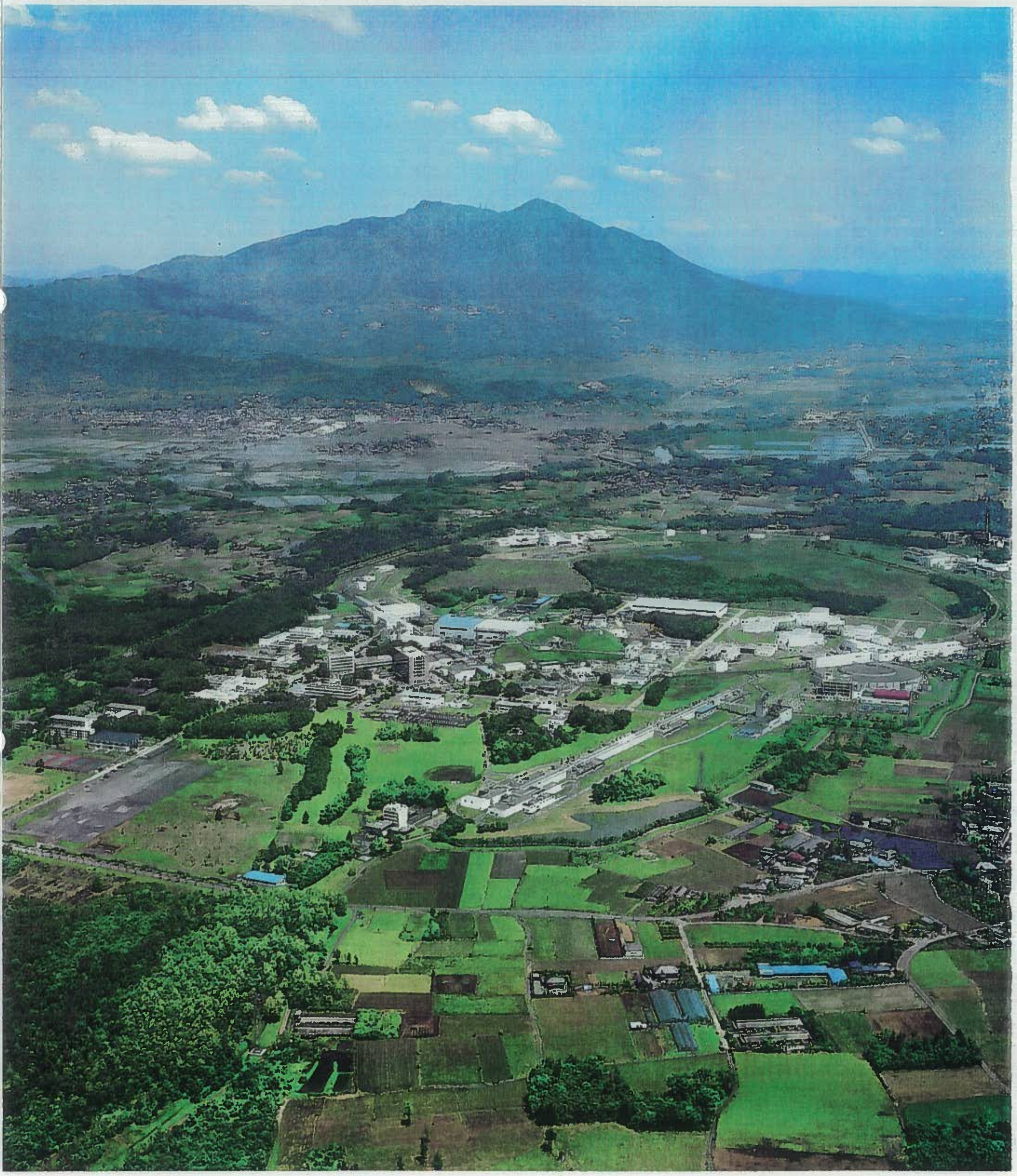
NTT Interdisciplinary Research Laboratories

The goals of NTT Interdisciplinary Research Laboratories are not only to contribute to NTT's telecommunications business but also to create new enterprises, advance academic fundamental research, and find solutions for environmental problems. To accomplish the above, we are carrying out research and development in a wide yet consistent spectrum, ranging from materials and equipment to systems development. The foundation of our work consists of three major research and development areas: (1) Optical interconnections, (2) Advanced multimedia hardware, and (3)Telecommunication energy/Innovative new materials.



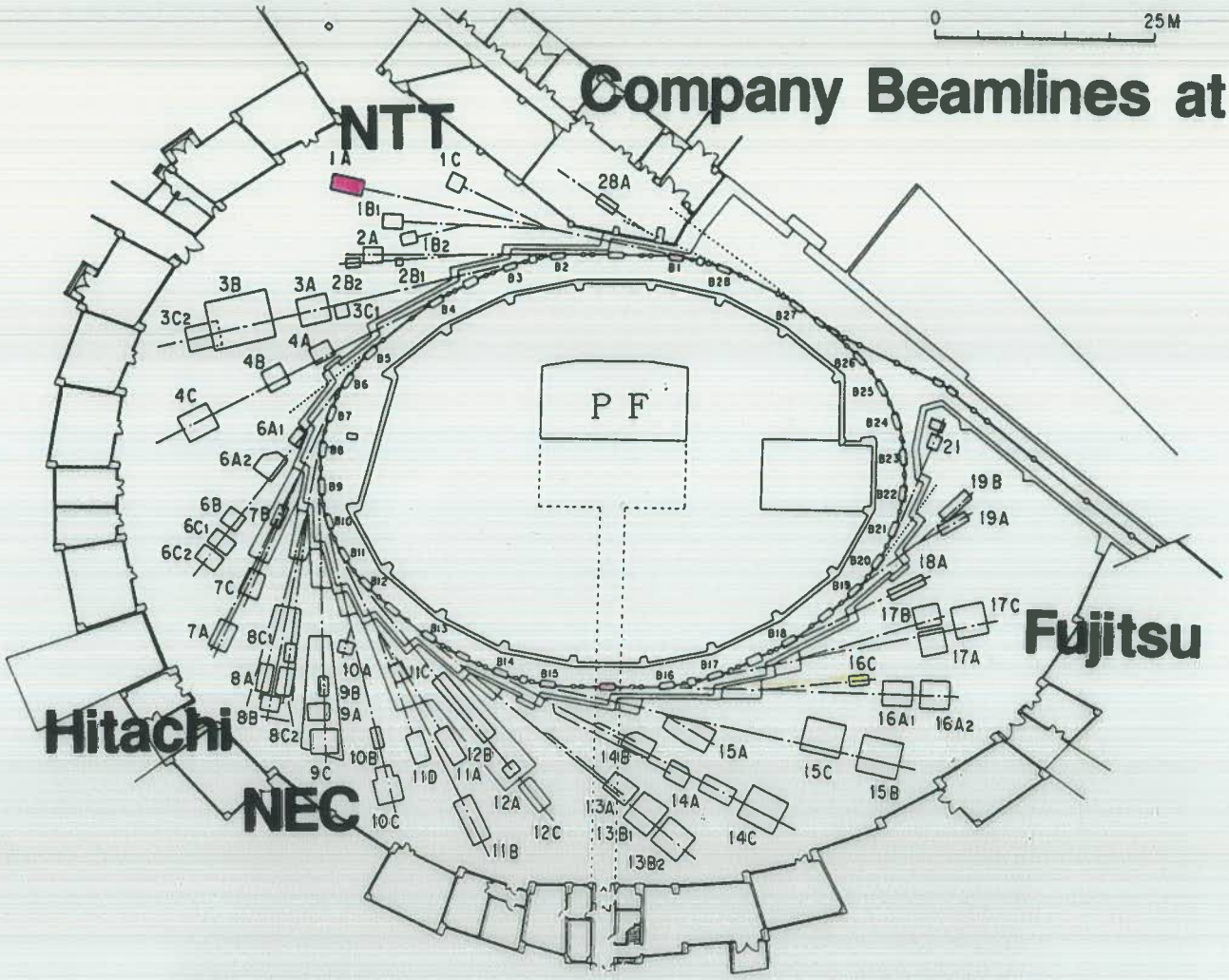
文部省

高エネルギー物理学研究所



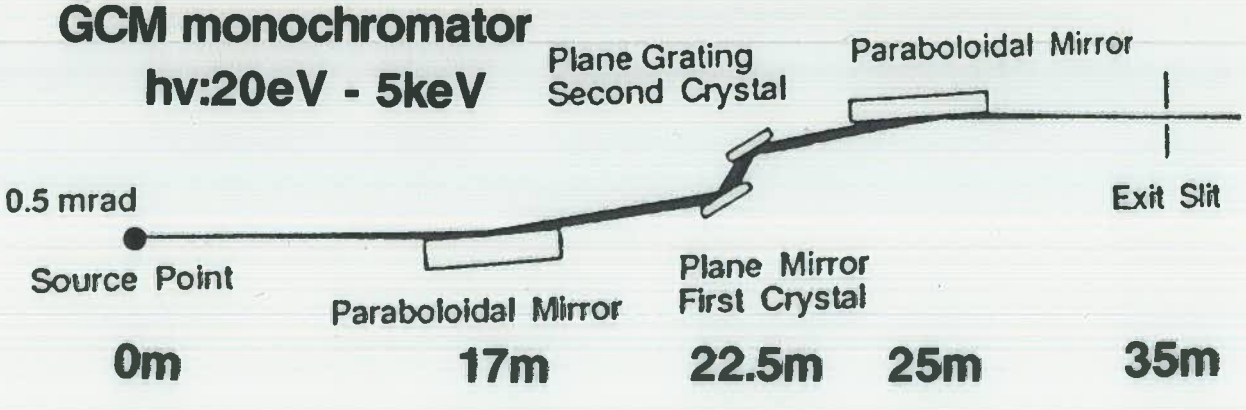
Bird's-eye view of the 2.5 GeV Linac, the 2.5 GeV PF Ring, the 6.5 GeV AR and the 30 GeV Main Ring.

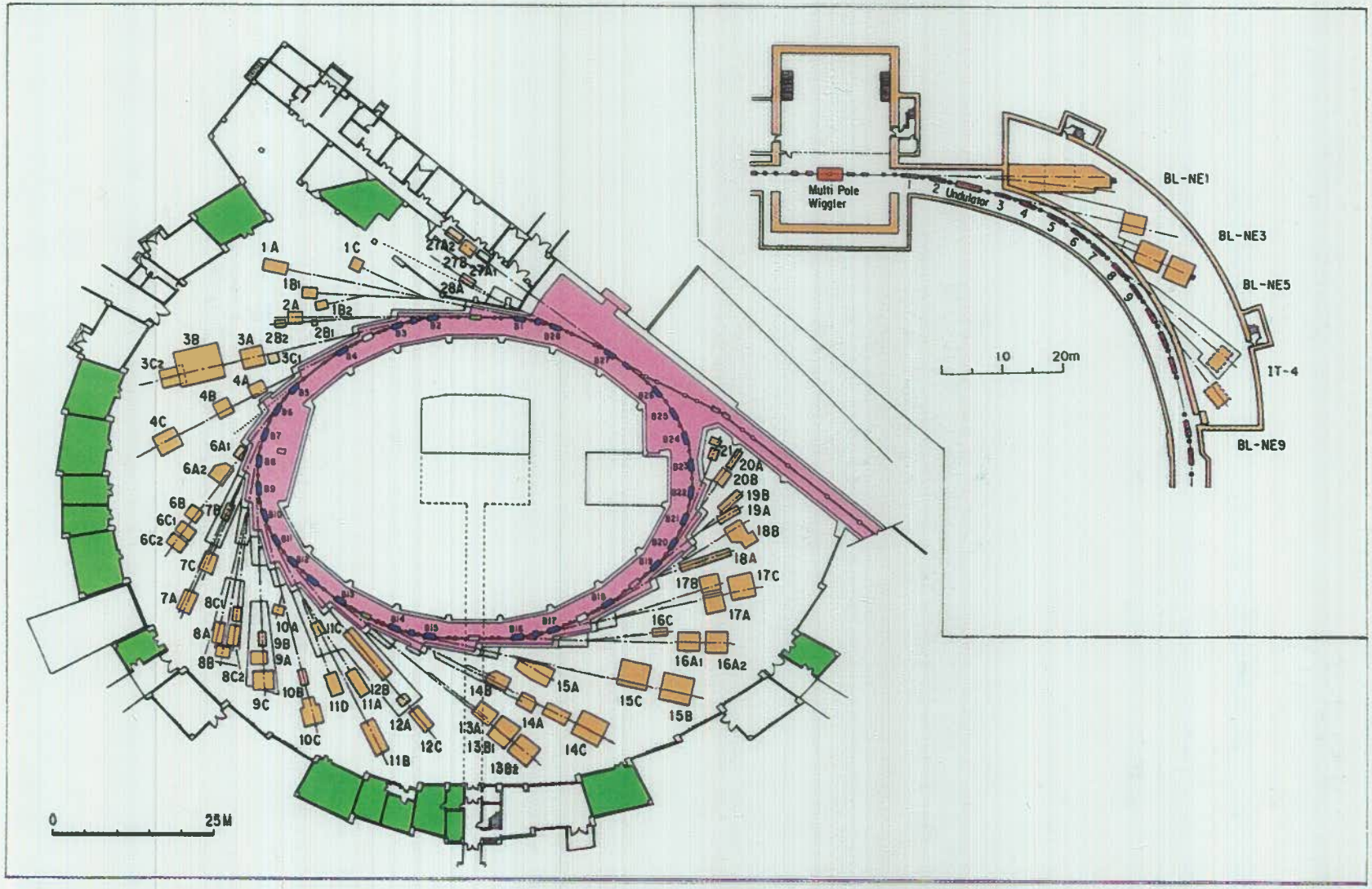
Company Beamlines at PF



GCM monochromator

hv:20eV - 5keV





The PF and the AR experimental areas

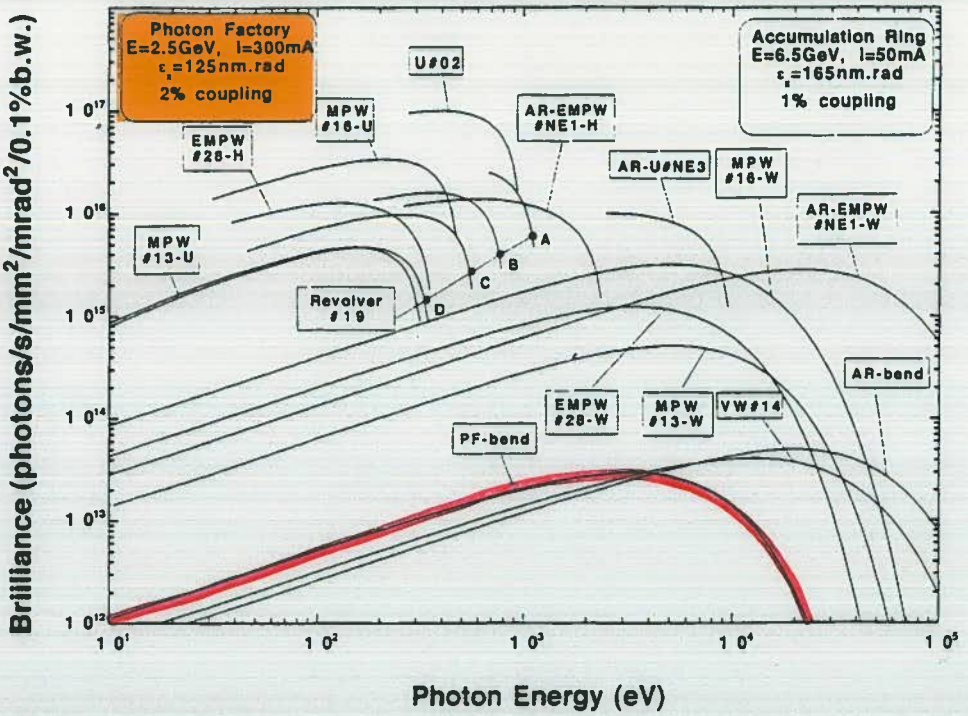
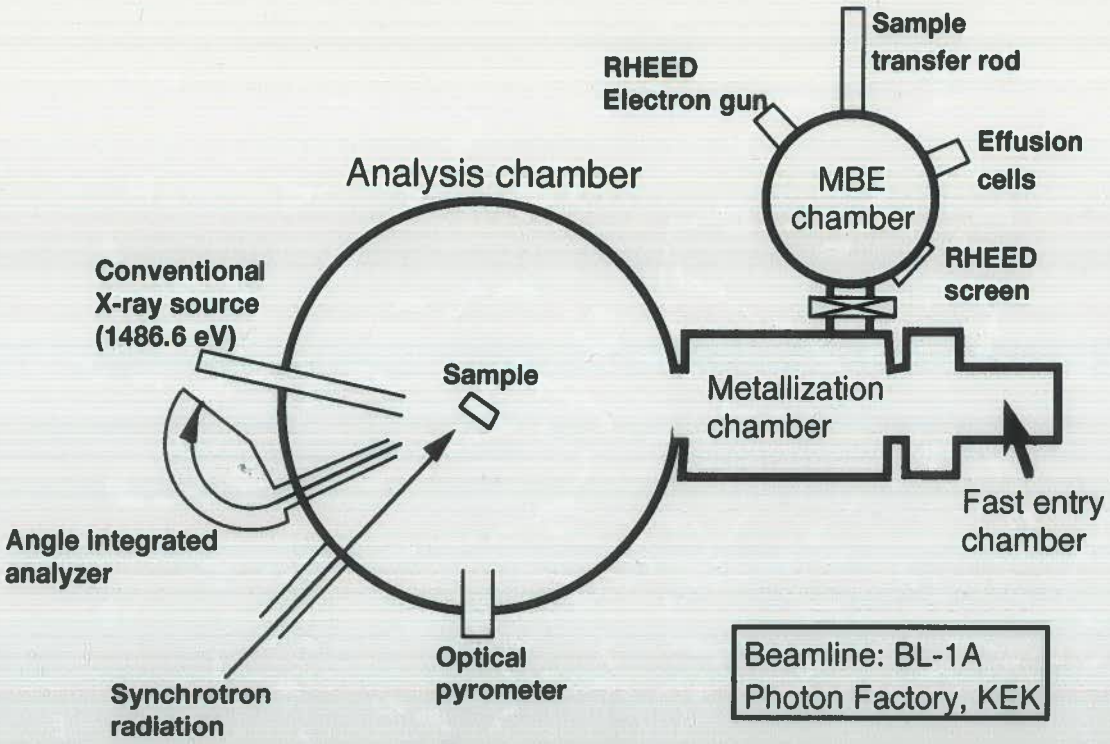


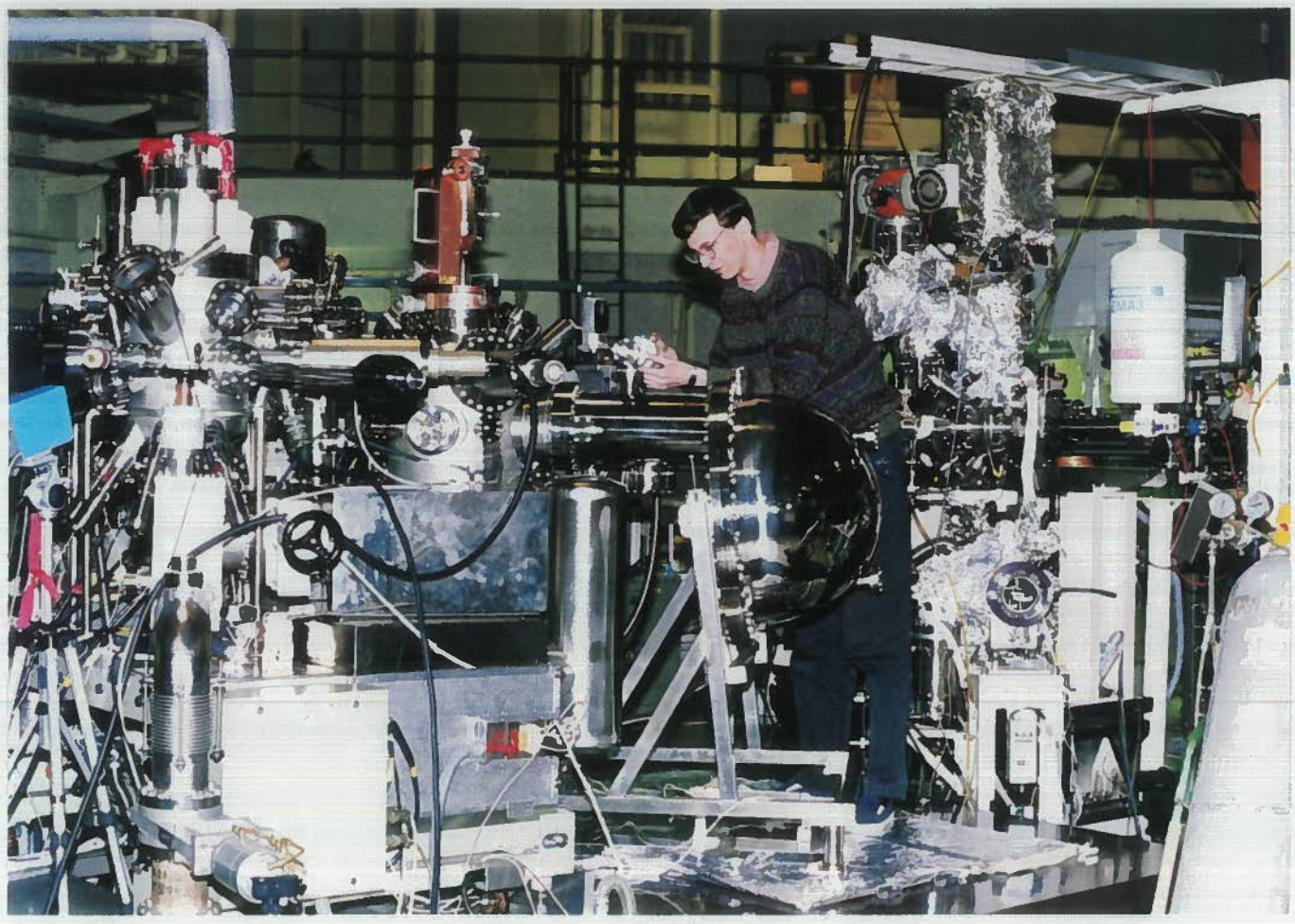
Fig. 12 Synchrotron radiation spectra.
Brilliance of radiation vs. photon energy for the insertion devices (U#02, MPW#13, VW#14, MPW#16, Revolver#19 and EMPW#28) and the bending magnet (Bend) of the PF, and for the insertion device (EMPW#NE1) of the AR. The name of each source is assigned in Table C-4. Several insertion devices have both undulator and wiggler modes, which are denoted by U or W, respectively. The spectral curve of each undulator (or undulator mode of multipole wiggler) is a locus of the peak of the first harmonic within the allowable range of K-parameter. Spectra of Revolver#19 are shown for four kinds of period lengths.

Table 9 General parameters of the storage ring.

Energy	2.5 GeV	(0.75 GeV to 3 GeV)
Initial stored current	(multi-bunch)	350 mA (max 500 mA)
	(single bunch)	60 mA (max 104 mA)
Emittance	130nm·rad(horizontal) ~2nm·rad(vertical)	
Circumference	187m	(bending radius=8.66m)
RF frequency	500MHz	(harmonic number=312)
Injection	2.5GeV Linac	(positron/electron)
Beam lifetime	60 h (at 300 mA)	$I\cdot\tau \geq 18$ A·h (at ~250 mA ~ 350 mA)
Vacuum pressure	$\geq 3\times10^{-10}$ Torr (at 300mA) P/I ~ 8×10^{-10} Torr/A (at ~250 mA ~ 350 mA) ~ 3×10^{-11} Torr (at 0 mA)	
Insertion devices	Superconducting vertical wiggler 5T 60 period undulator K=1.78~0.1 26 period multipole wiggler/undulator 1.5T~0.04T Four way revolver type undulator 14 period multipole wiggler Elliptically polarized multipole wiggler	
SR channels	SR experiment 22 Beam diagnosis 3	



In situ surface analysis system



Alkaline Earth Fluorides on Semiconductors

New possibilities for dielectric insulation and passivation (FET) (Farrow / Ishiwara)

+ lattice matching to semiconductors (SrF_2 on InP: -1.2%) CaF_2 : 5.5 Å to BaF_2 : 6.2 Å
+ good insulators (band gap: 10 -12 eV)
+ fluorite structure similar to diamond or zinc blende structure of semiconductors
+ sublime as molecules (stoichiometry OK)

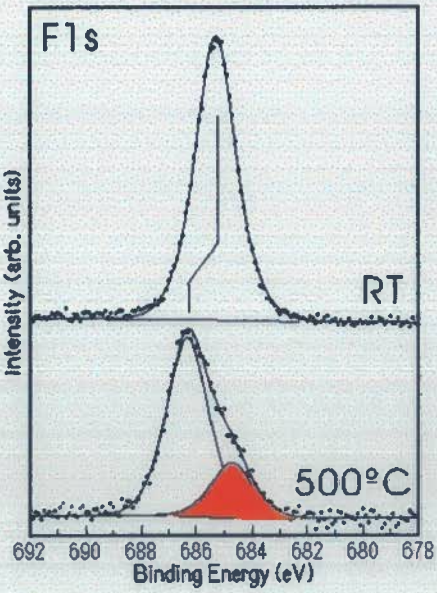
perfectly ordered heteroepitaxial crystalline insulator - semiconductor interface (superior transport properties)

NTT

Interfacial Reaction

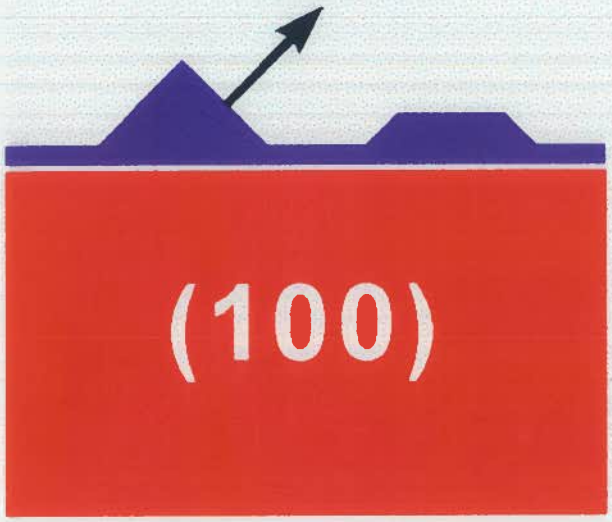
e.g. SrF_2 on InP(111)

Heun et al,
PRB 52 (1995) 14917



Facets

<111>



Layer

Hannover
(Germany)
Prof. Henzler
Dr. Wollschläger

11/93

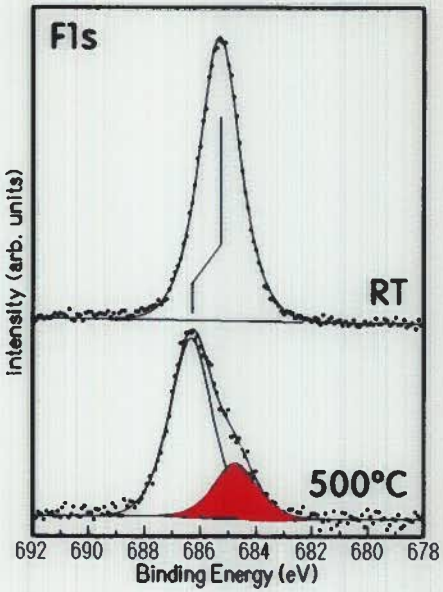
NTT
(Japan)

06/95

Trieste
(Italy)
Dr. Sorba

SrF_2 on InP

4 int. conf.
(ALE, MBE,
ICG, IPRM)
4 paper
(ASS, JCG,
2 x PRB)

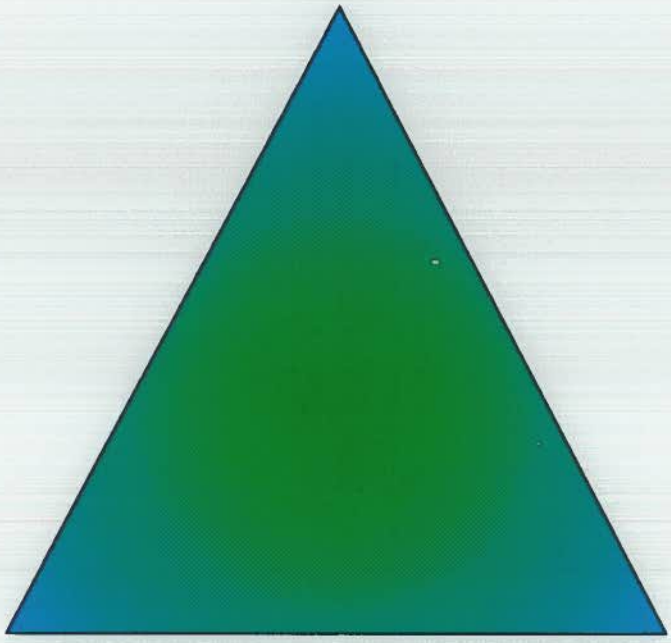


CaF_2/Si/GaAs

collaboration with
Dr. Wada,
NTT LSI Labs.
Quantum Dev. Lab.

The role of an Si ICL between GaAs and CaF_2

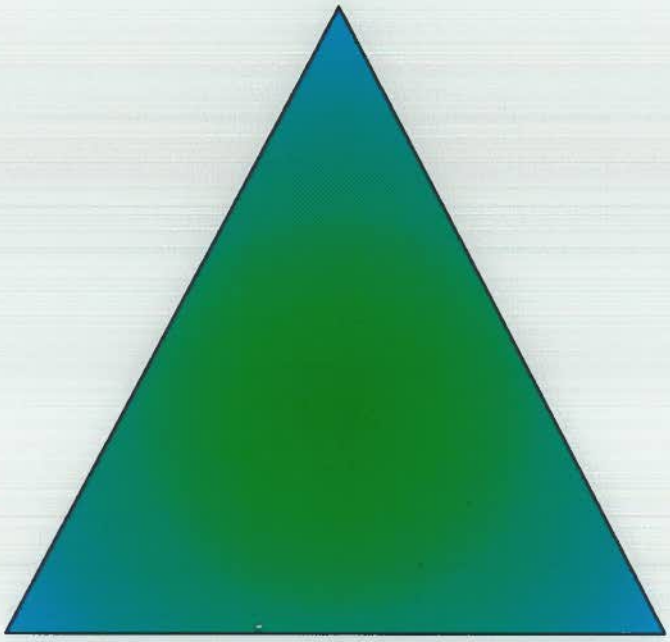
Film morphology (XRD, RHEED, SEM, AFM)



Electrical properties (C-V-curves)

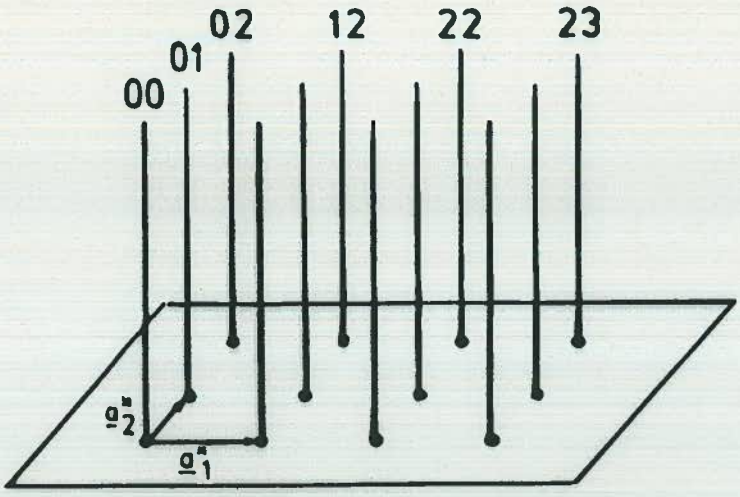
Chemical bonding (SRPES, XPS)

Film morphology (XRD, RHEED, SEM, AFM)

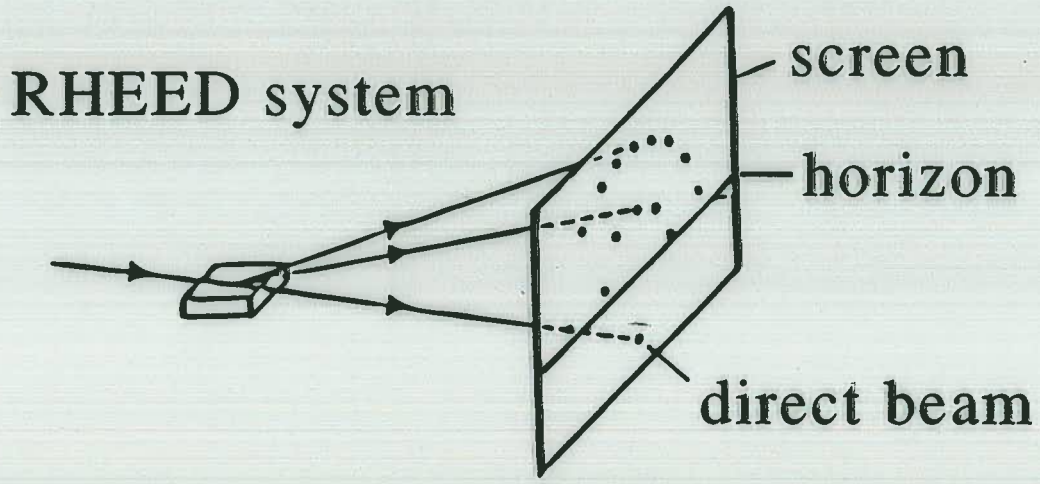


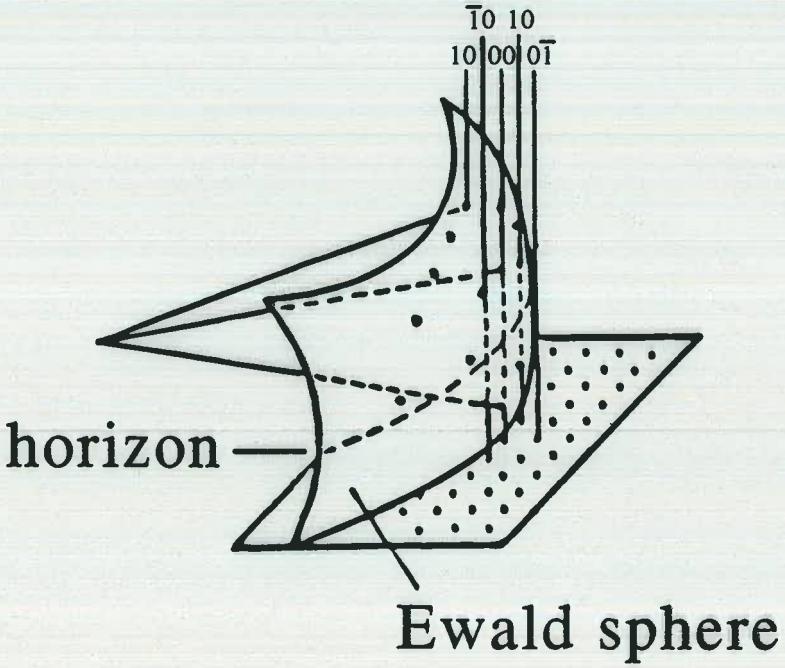
Electrical properties (C-V-curves)

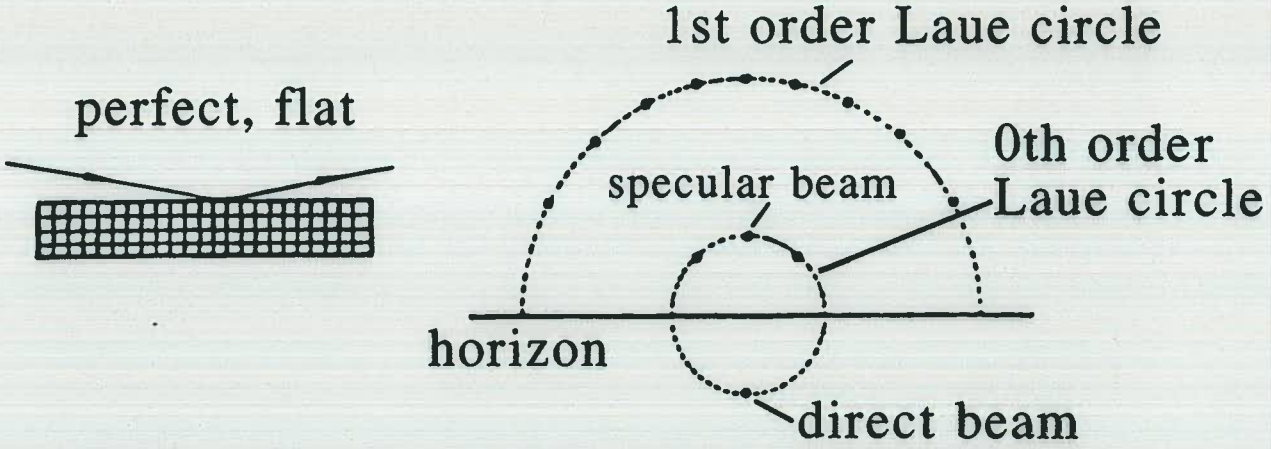
Chemical bonding (SRPES, XPS)

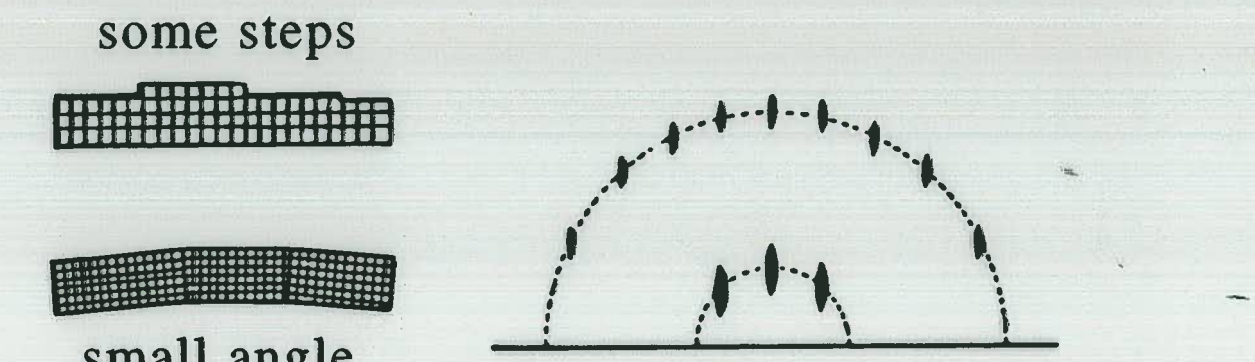


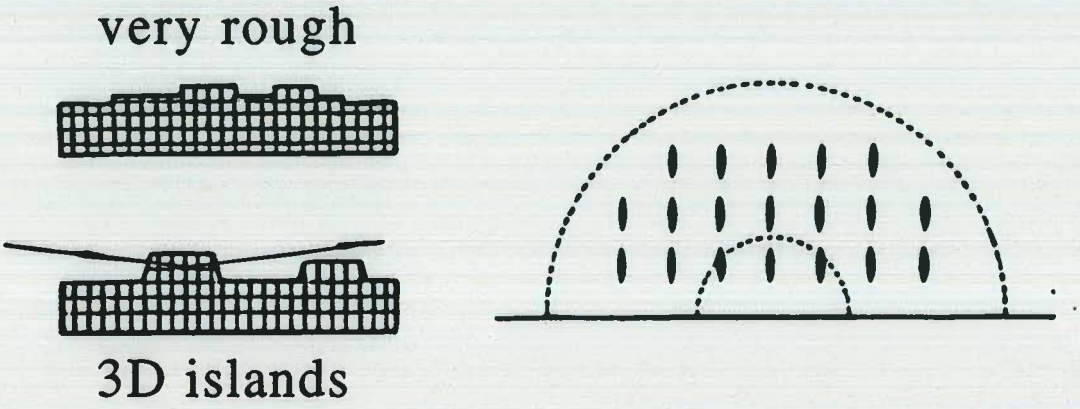
reciprocal space (CTRs)



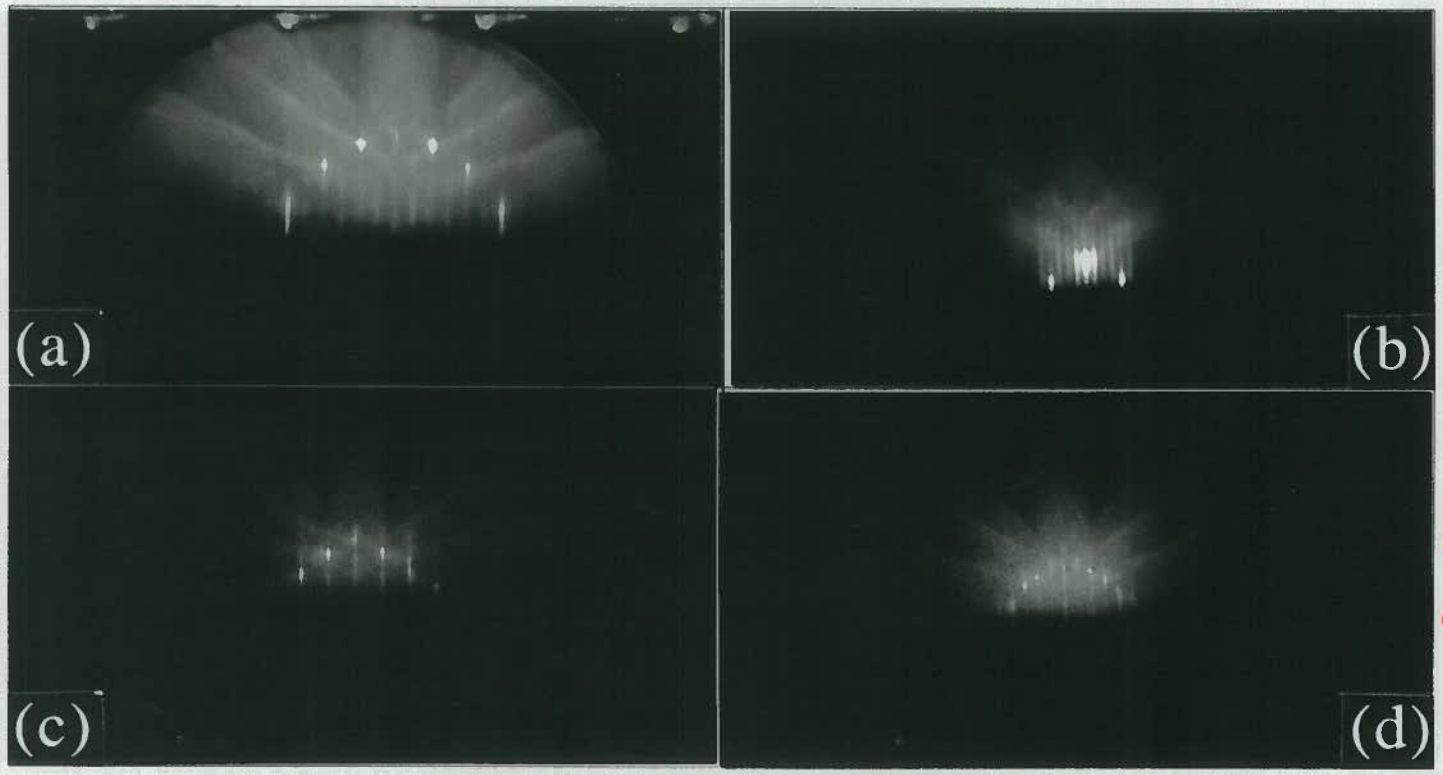



1st order Laue circle
perfect, flat
0th order
Laue circle
specular beam
horizon
direct beam


some steps
small angle
mosaic


very rough
3D islands

Si on GaAs (100) - (2×4)



clean GaAs 2×4

2ML Si at 500°C

1×2

[011] [0$\bar{1}$1]

GaAs (100) - (2×4)

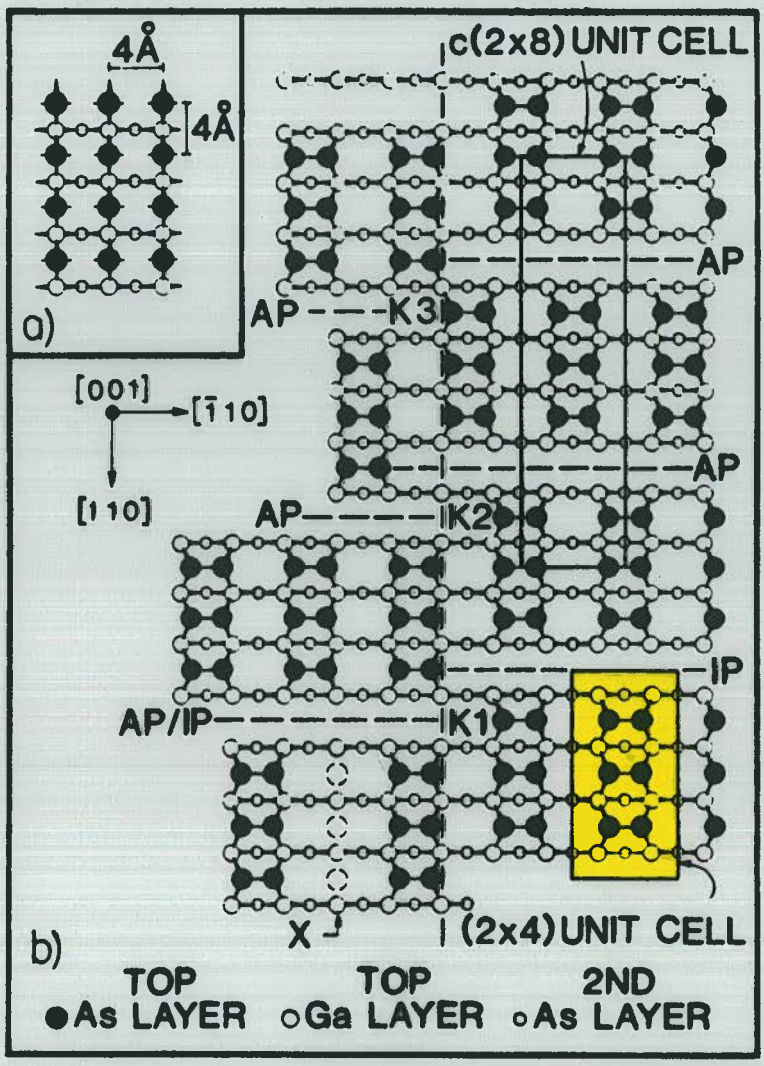
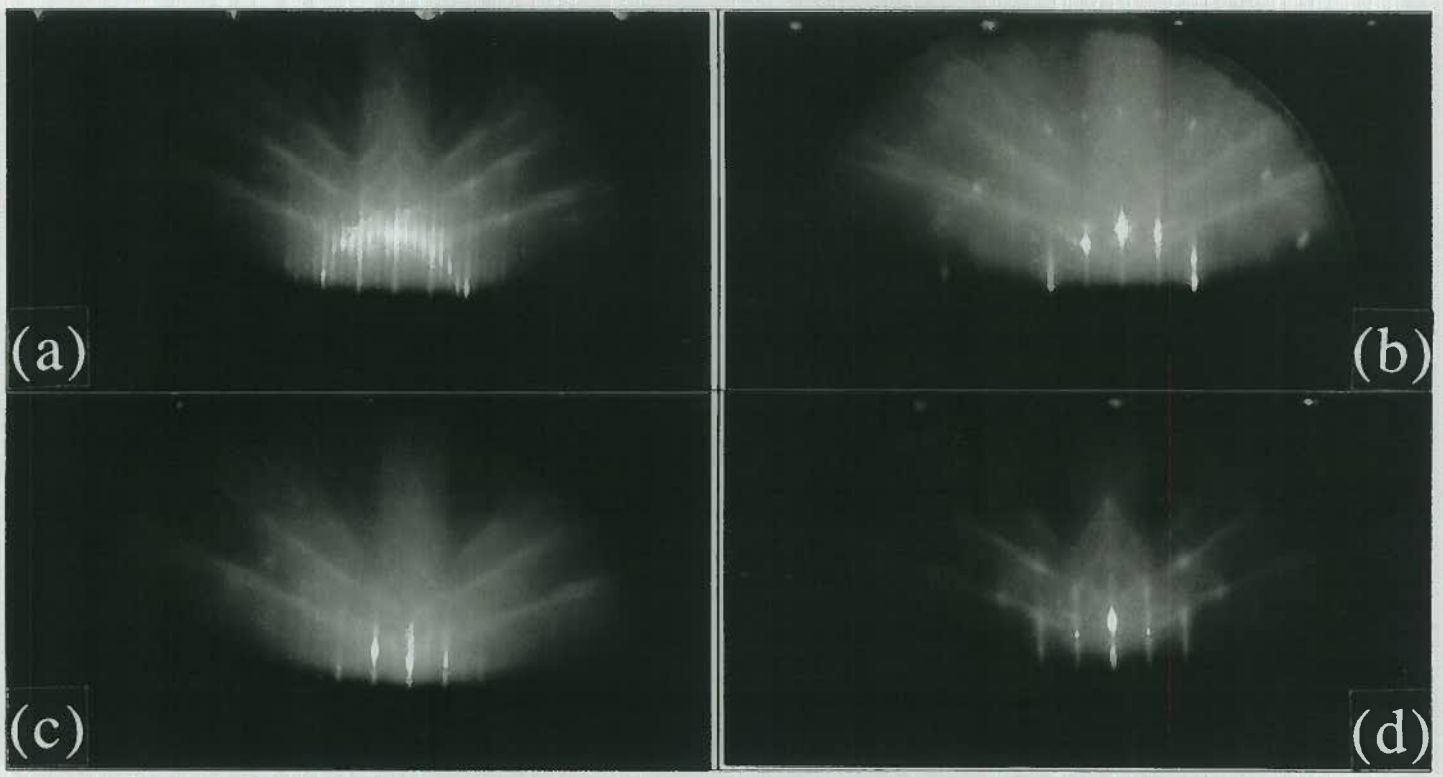


FIG. 1. (a) The structure of the unreconstructed GaAs(001) arsenic-rich surface. (b) The missing-dimer model for the GaAs(001) (2×4) surface. The two types of missing-dimer boundary, in-phase (IP) and antiphase (AP), are shown giving rise to (2×4) and $c(2\times8)$ structures. The intersection of a domain boundary along the [110] direction with the IP and AP boundaries is shown giving rise to three types of boundary kinks: K_1, K_2, and K_3. Disorder in the arsenic pairing (X) with three missing arsenic atoms (dashed circles) is also shown.

Si on GaAs (100)-c(8×2)



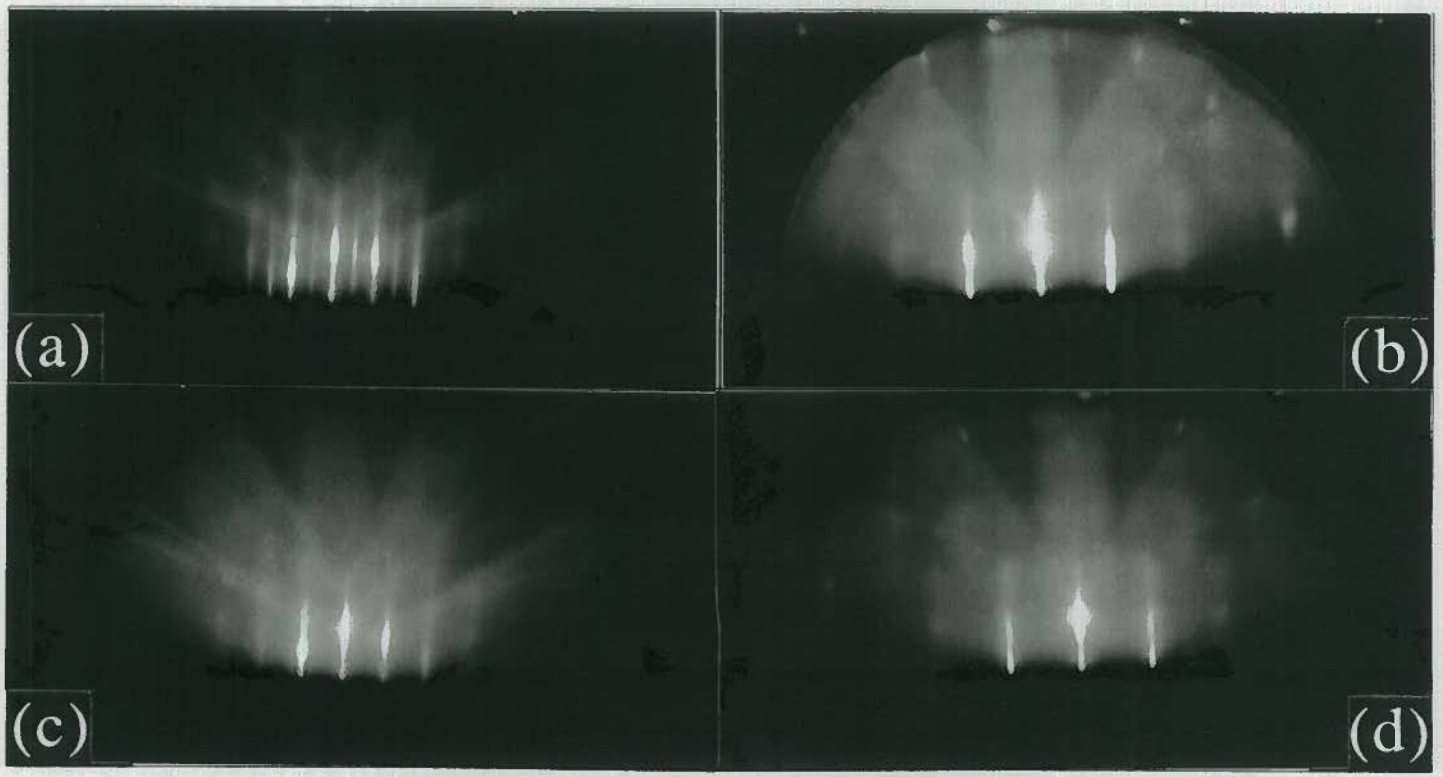
clean GaAs

c 8×2

0.5 ML Si at 450°C

2×1

Si on GaAs (111) A - (2×2)



clean GaAs

2×2

0.5 ML Si at 450°C

1×1

GaAs (111) A - (2×2)

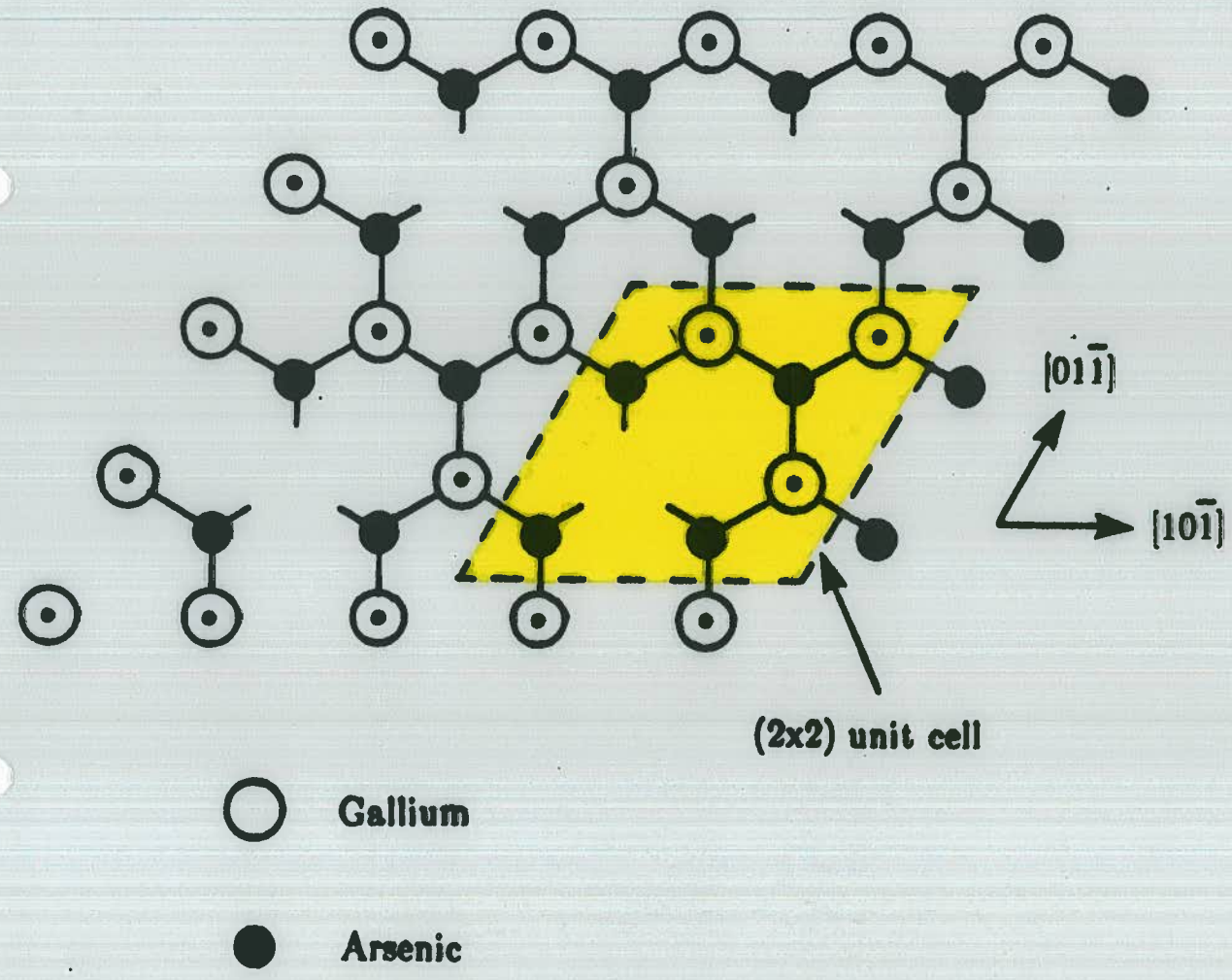
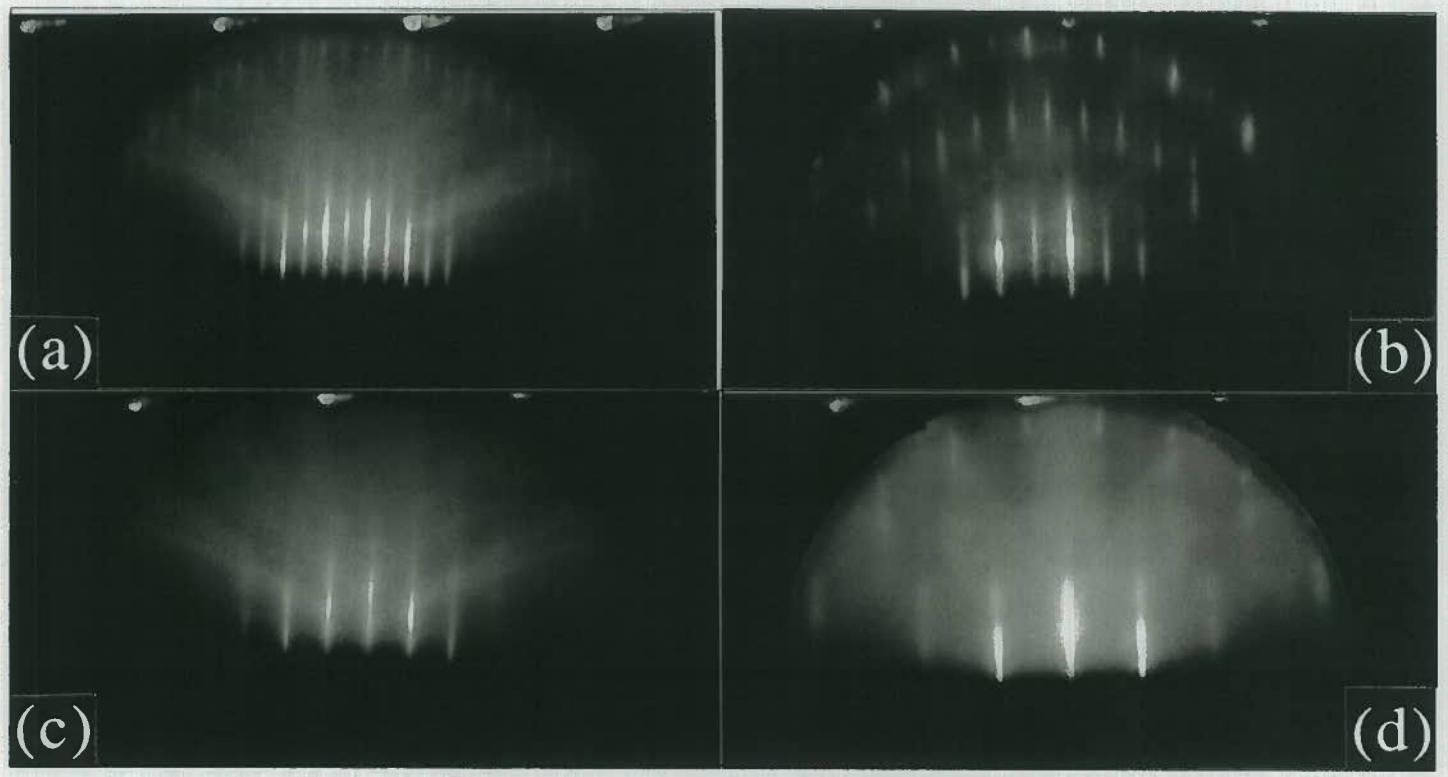


FIG. 1. Top view of the single–gallium-vacancy model of the GaAs(111)*A*-(2×2) reconstruction proposed by Tong *et al.* (Ref. 4) showing the surface gallium atoms and the arsenic atoms immediately below. The (2×2) unit cell is 8 Å on the side. Dangling bonds on the arsenic atoms resulting from the gallium vacancy are shown. The gallium dangling bonds out of the surface are shown as dots on each gallium atom.

Si on GaAs (111)B -(2×2)



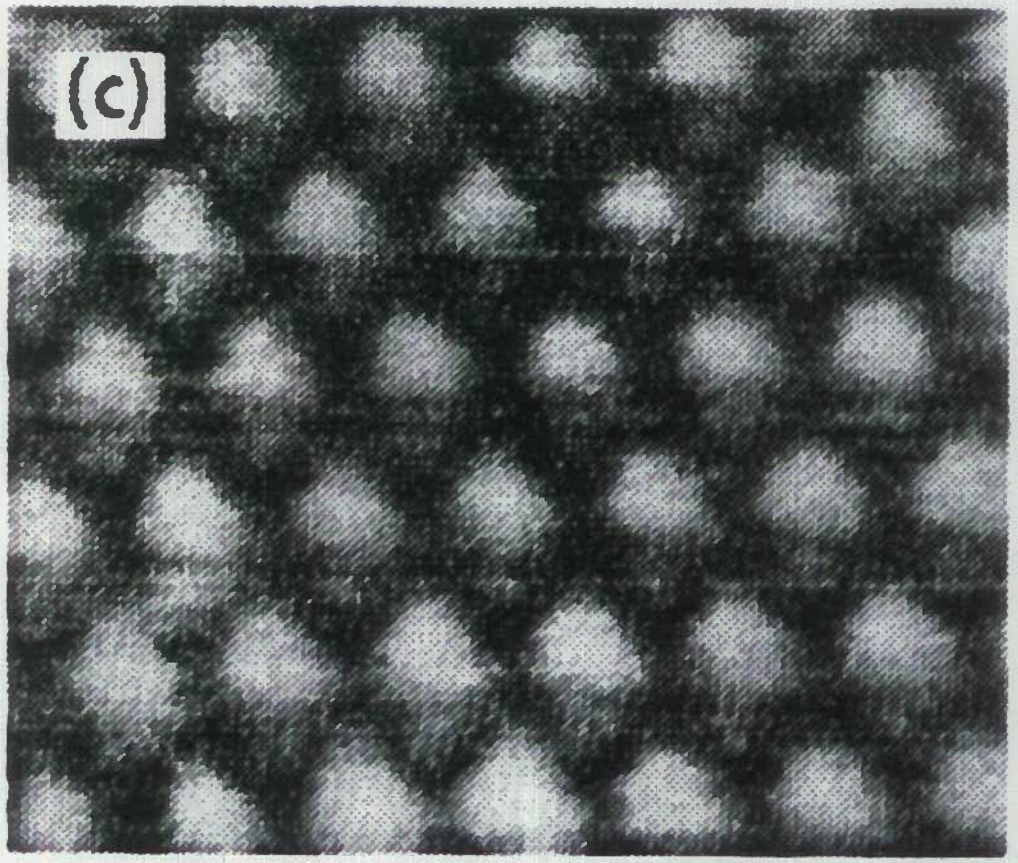
clean GaAs

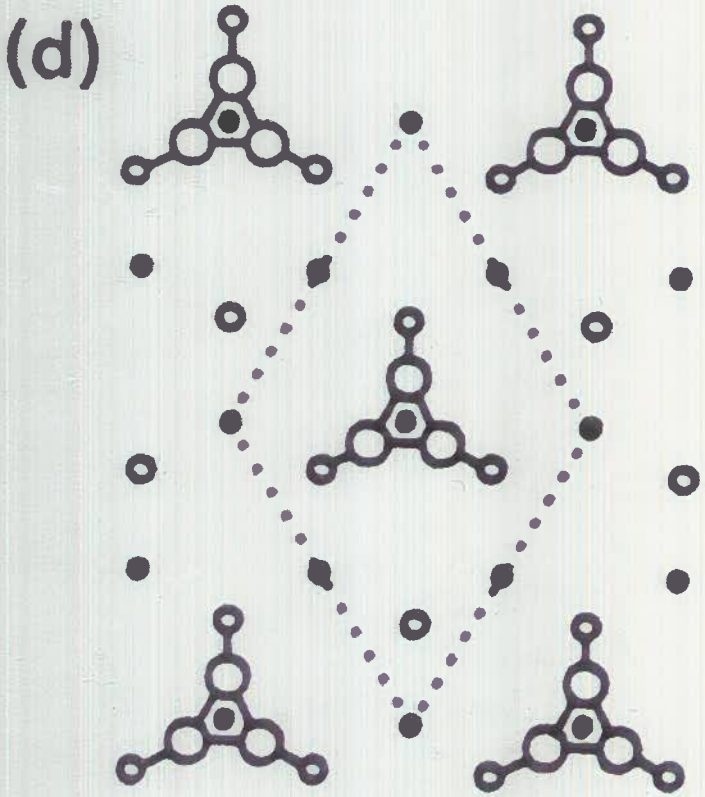
2×2

0.5 ML Si at 450°C

1×1

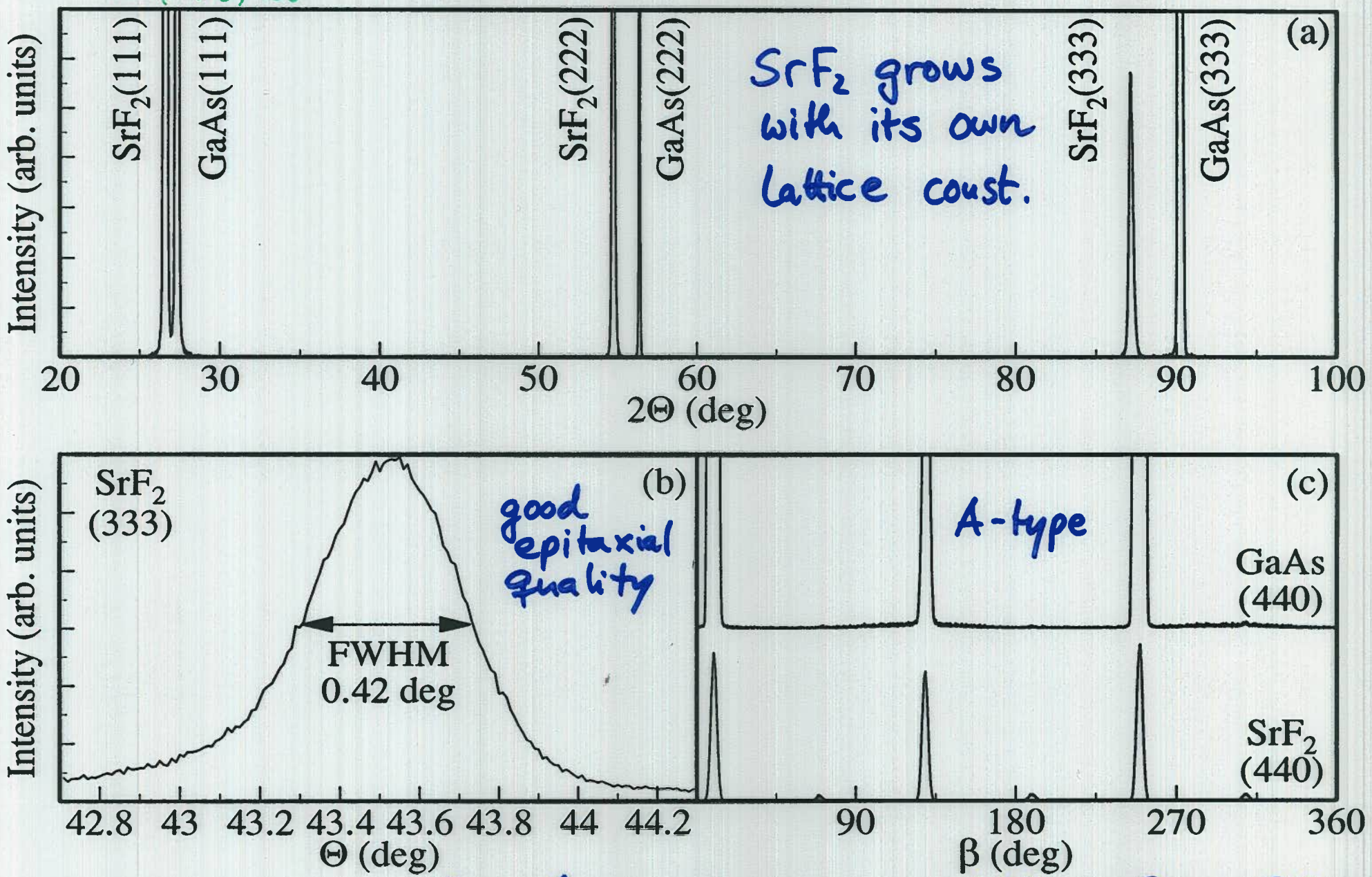
GaAs (111) B - (2×2)





Biegelsen et al.: PRL 65 (1990) 452

Heun et al.: Materials Sci. Forum 203 (1996) 129

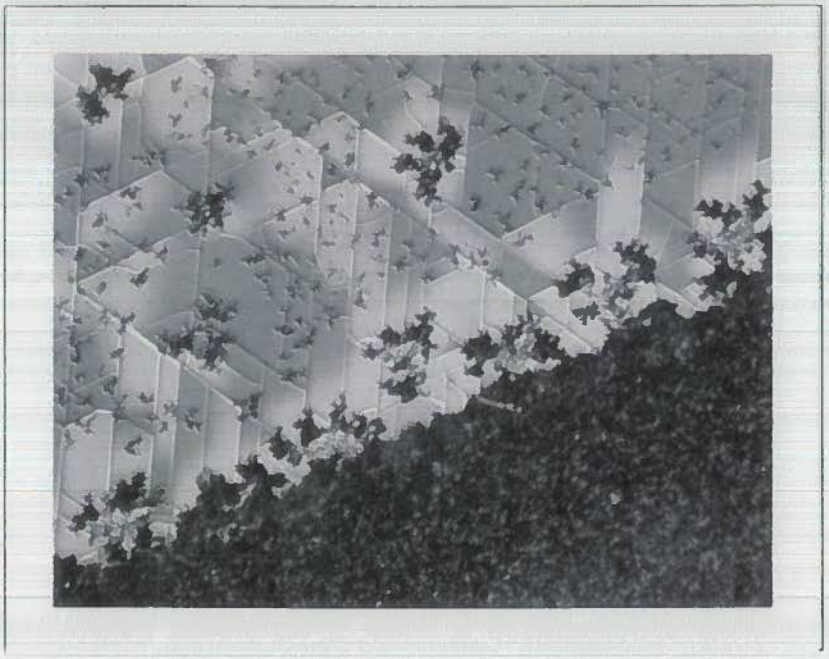


SrF_2 on Si / GaAs(111)

Ishiwara: SrF_2 on Si(111): B
SrF_2 on GaAs(111): A

Relaxation of lattice mismatch by dislocations

1000Å SrF_2 on 8ML Si on GaAs(100)-(2x4) at 500°C, x1000



3000Å SrF_2 on 1.5ML Si on GaAs(111)A at 530°C, x500

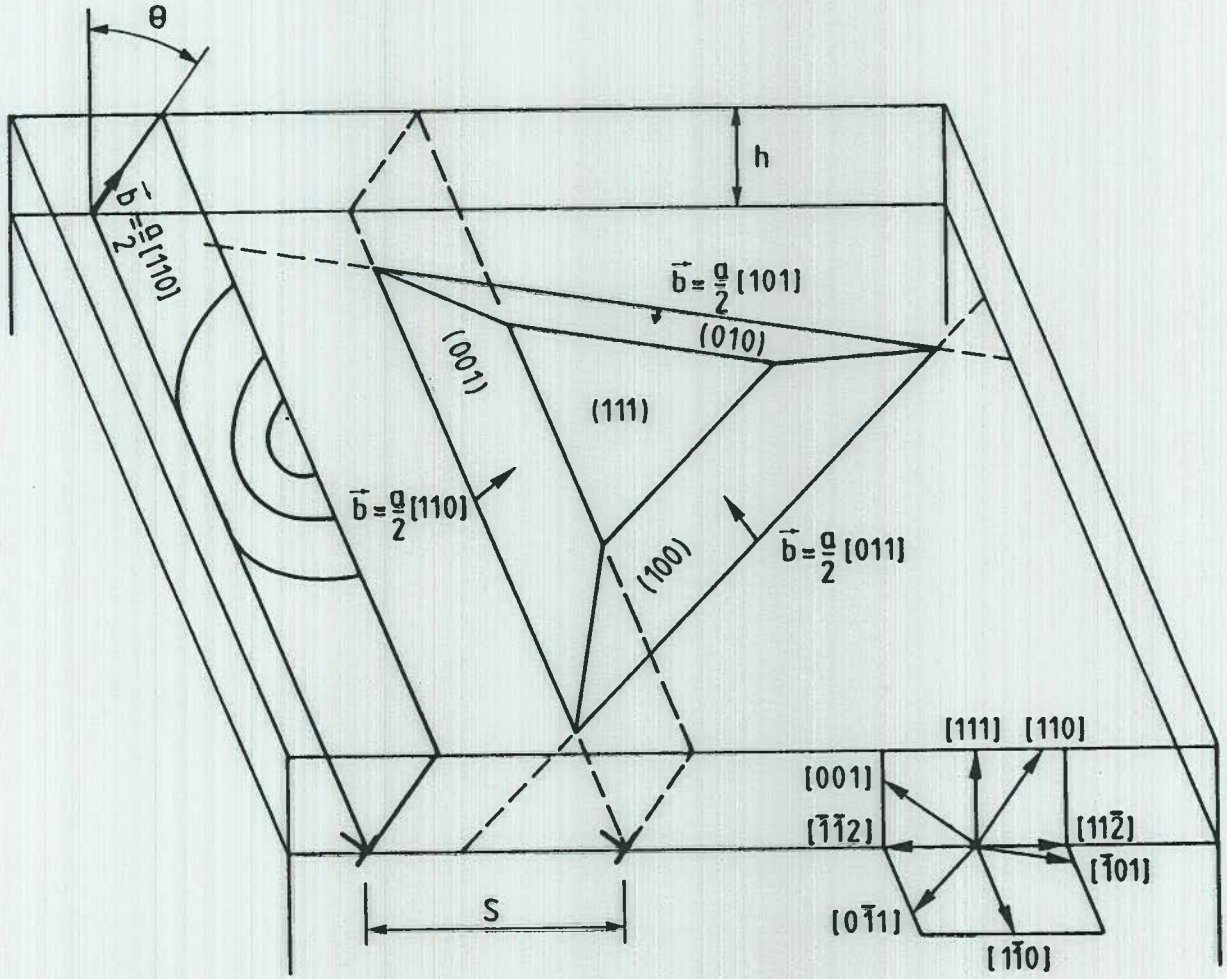
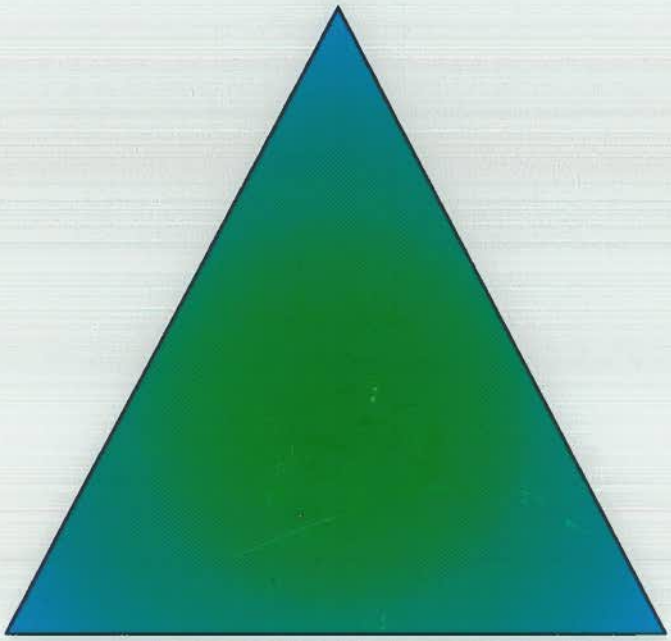


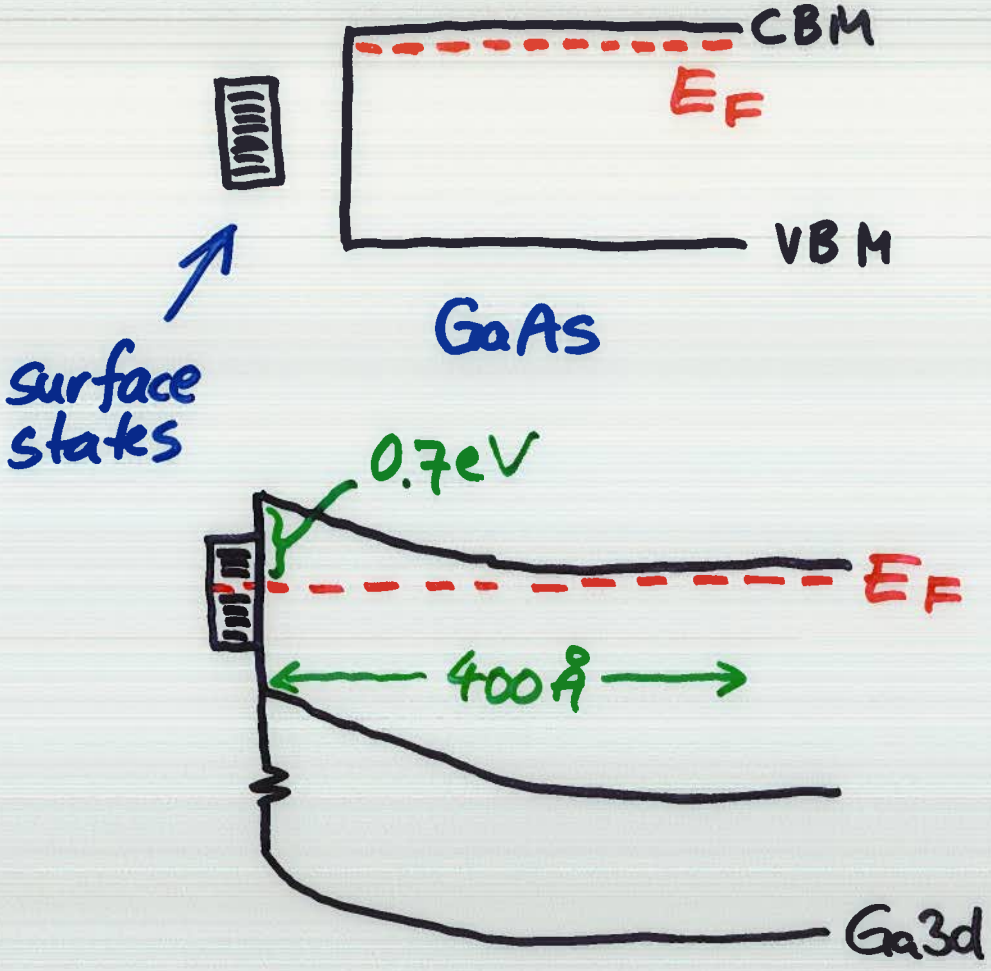
FIG. 2. Schematic drawing of dislocation nucleation and glide in the primary {100}⟨110⟩ system for (111)-oriented films.

Film morphology (XRD, RHEED, SEM, AFM)

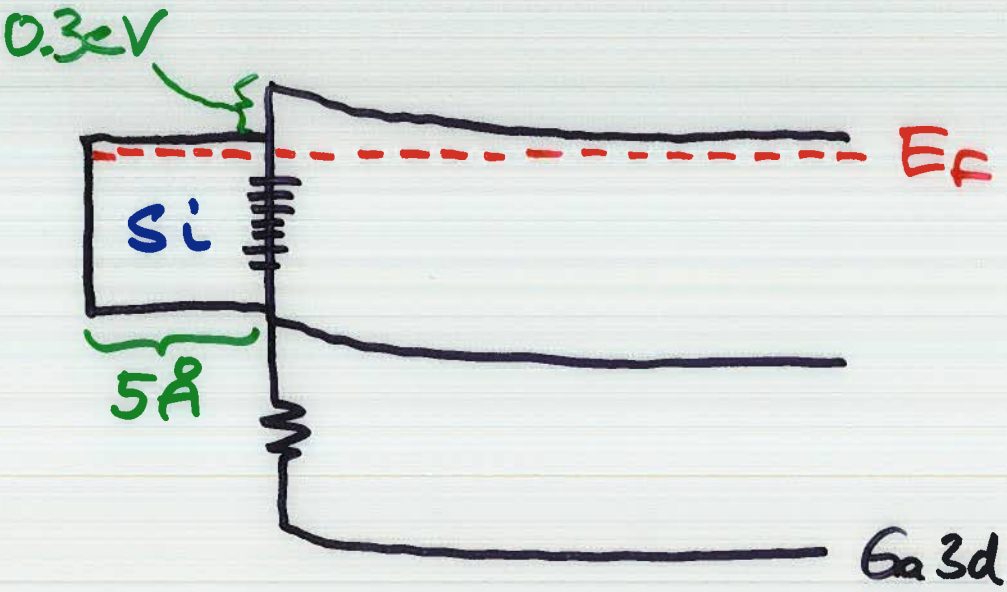


Electrical properties (C-V-curves)

Chemical bonding (SRPES, XPS)

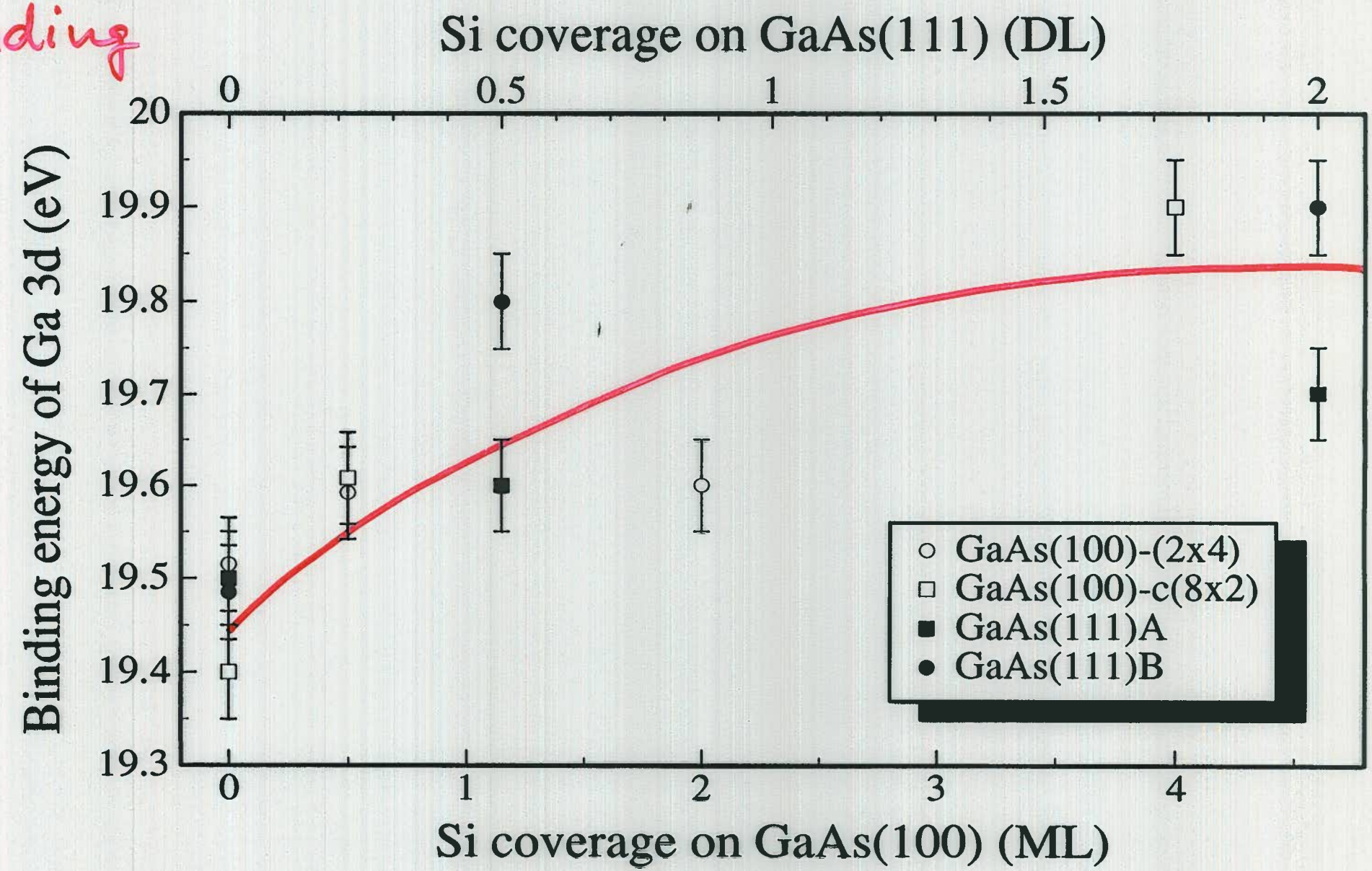


band bending

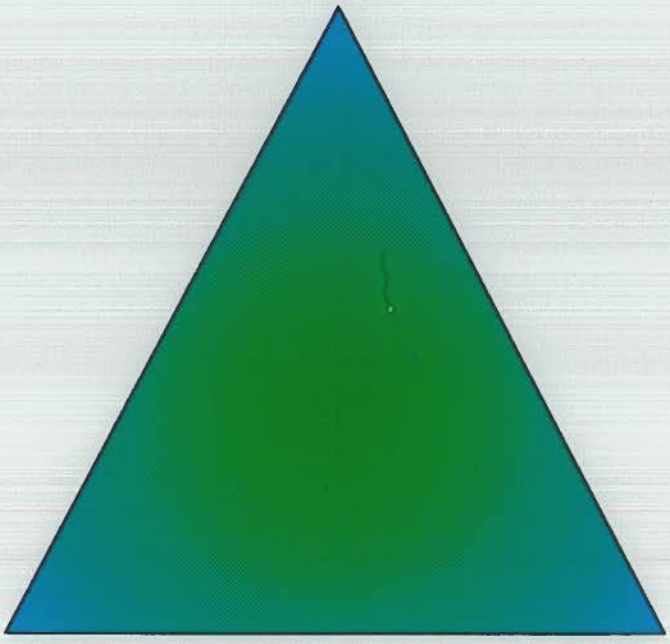


relaxation of band bending after deposition of Si

Relaxation of band bending



Film morphology (XRD, RHEED, SEM, AFM)



Electrical properties (C-V-curves)

Chemical bonding (SRPES, XPS)

Results

- distance between As 3d and Ga 3d bulk components is constant
  → assignment OK
- binding energy of the peaks in SRPES 0.1 ~0.2 eV smaller than in XPS → band bending model OK
- All doublets fitted with a fixed parameter set:

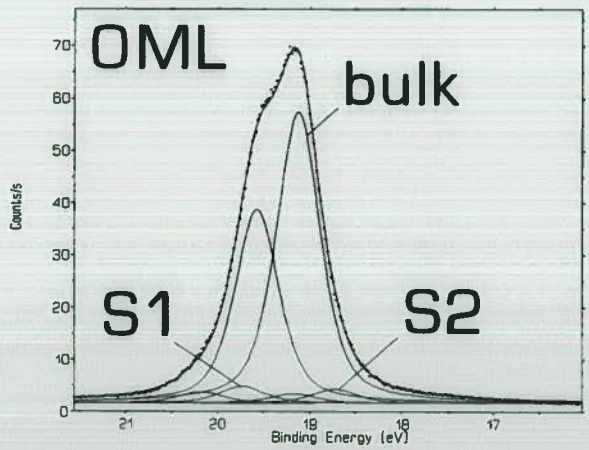
  Ga 3d: Voigt, FWHM = 0.55 eV, mix = 0.45
  Δ_{so} = 0.45 eV, BR = 1.5 [Le Lay]

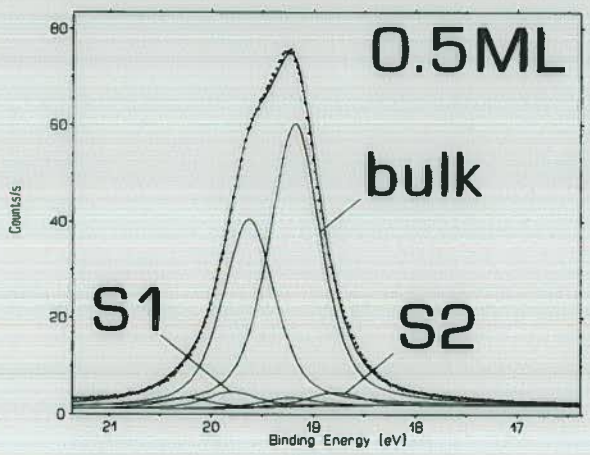
  As 3d: Voigt, FWHM = 0.65 eV, mix = 0.75
  Δ_{so} = 0.69 eV, BR = 1.4 [Le Lay]

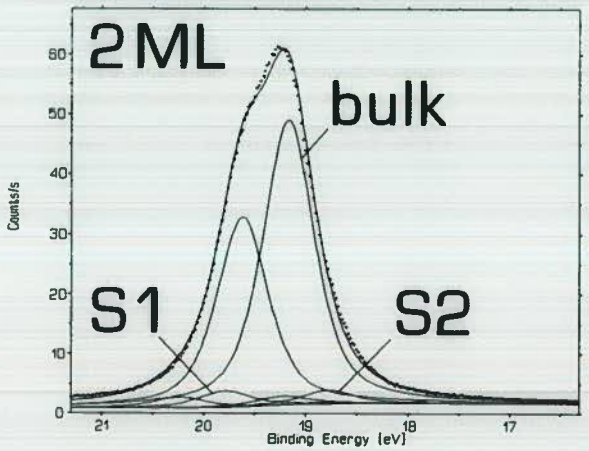
- peak positions, chemical shifts agree with literature values (if available)

Si on As-rich GaAs(100)

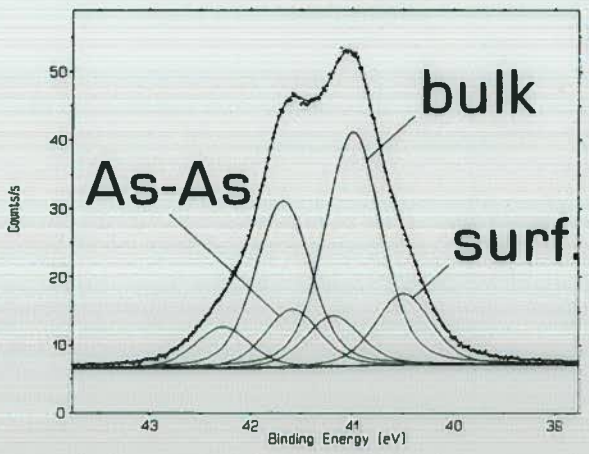
Ga3d





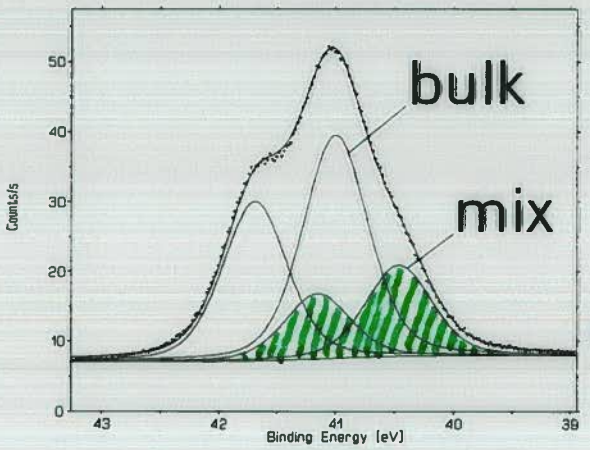


As3d

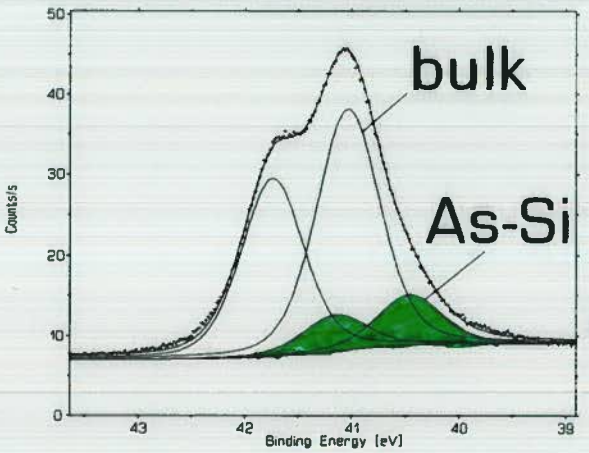


r = As/Ga

r = 0.3



r = 0.6



r = 0.

No As-segregation

? Why As-Si peak at lower binding energy ?

Electronegativities:

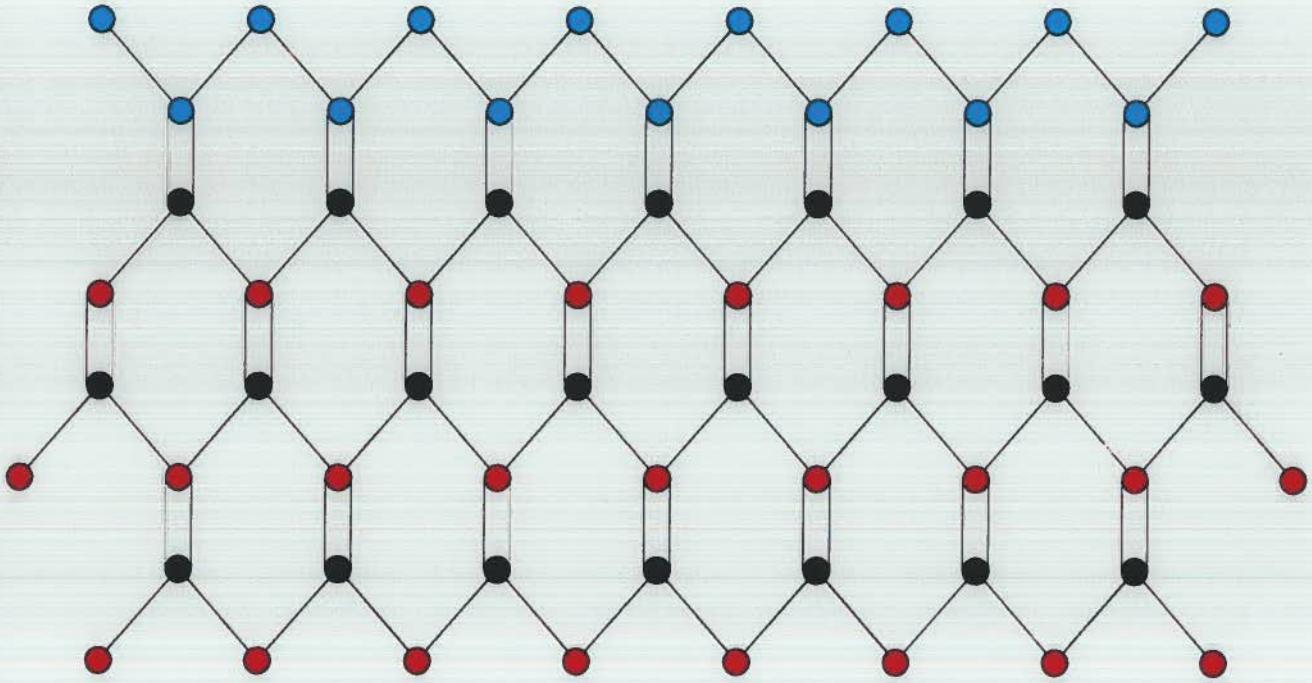
Ga 1.6
Si 1.8
As 2.0

Bachrach et al. (J. Vac. Sci. Technol. B5 (1987) 1135) found the same

→ Madelung energy must be taken into account

(cf. Gates (10), Davenport et al. Solid State Comm. 40 (1981) 999)

Si on As-rich GaAs(100)

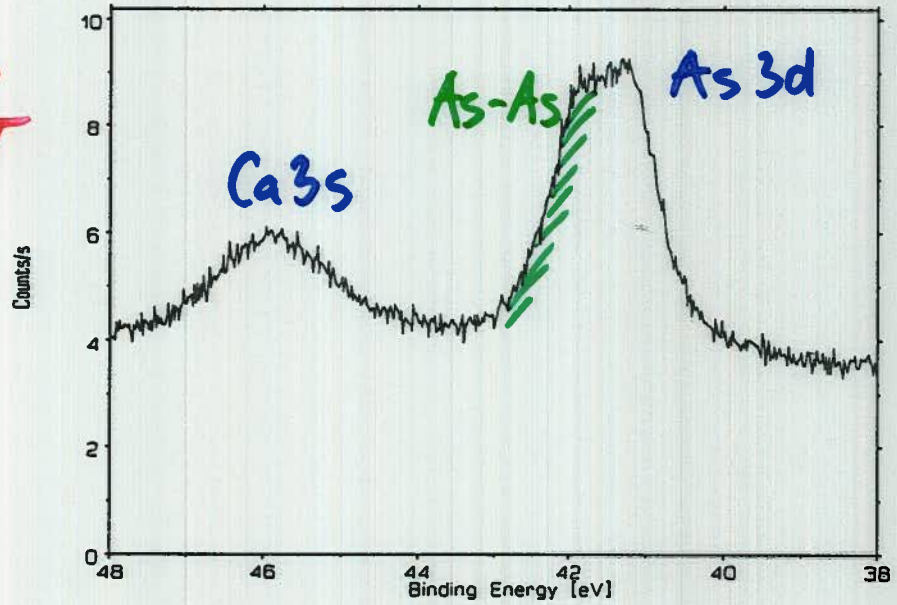


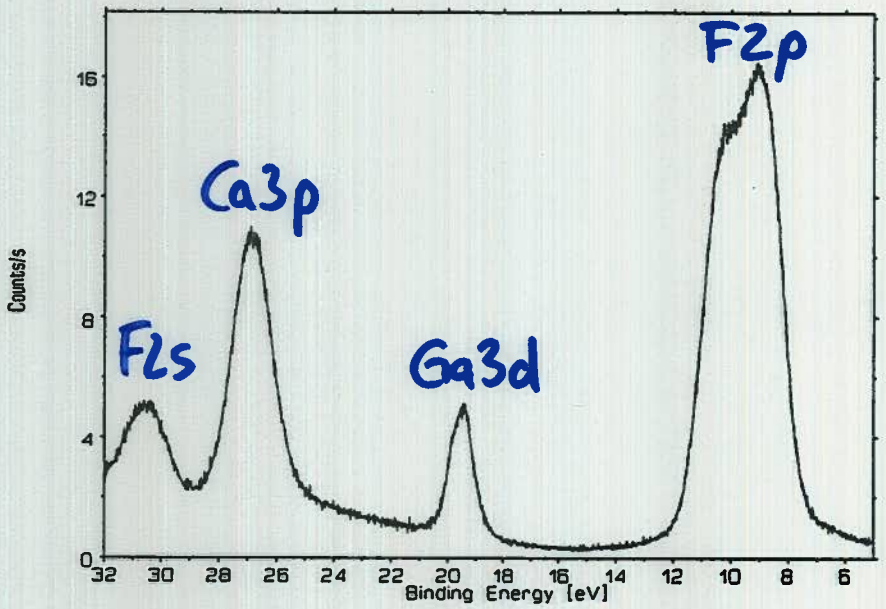
• Ga • As • Si

12Å CaF_2 / 2ML Si / As-rich GaAs(100)

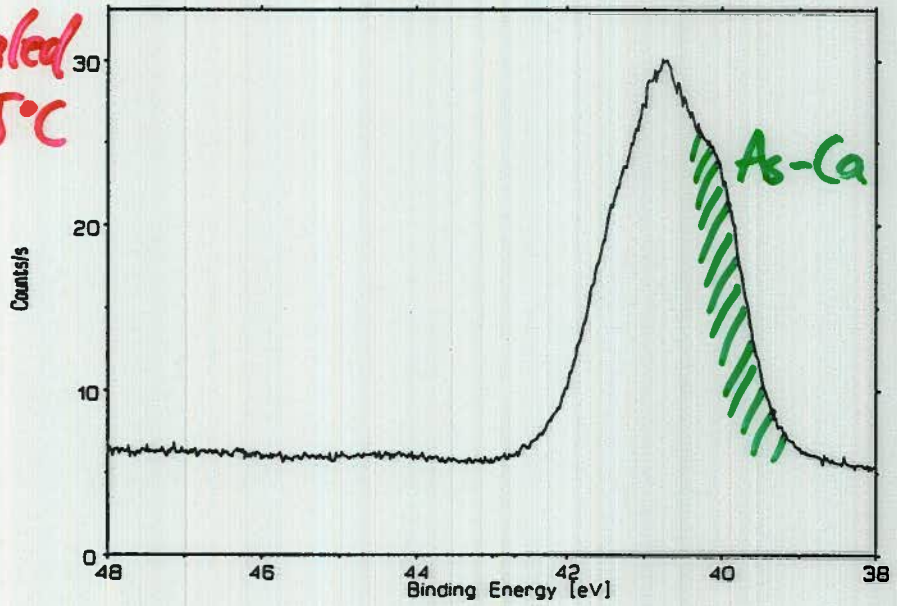
BB = 0.5eV

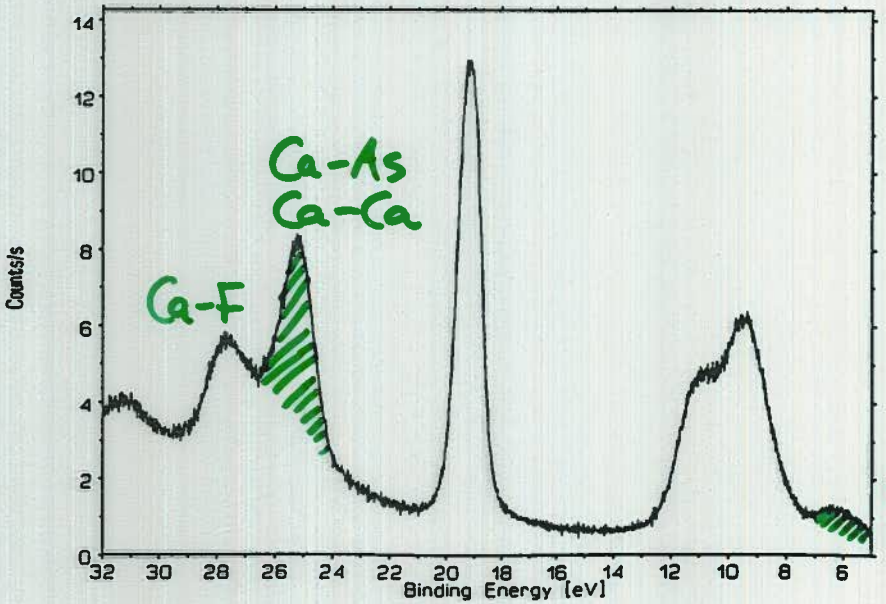
depo. at RT





annealed at 645°C



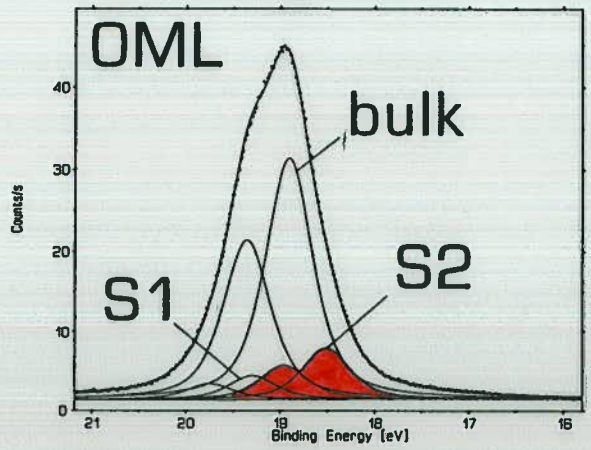


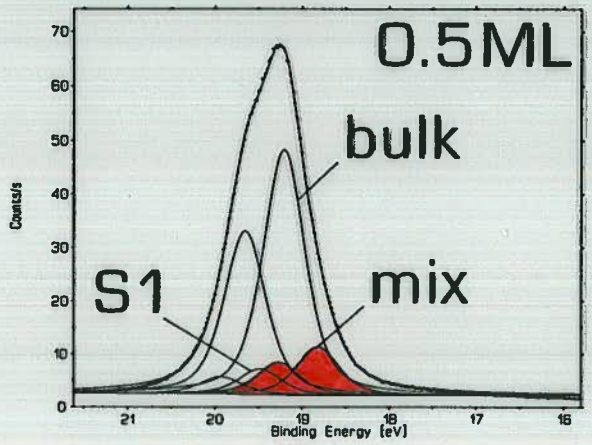
GaAs VB

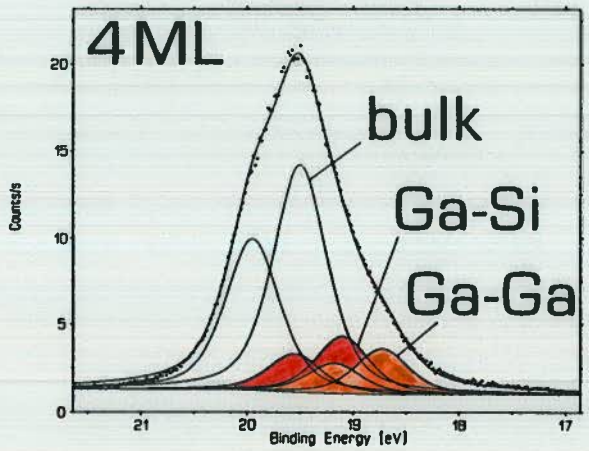
-c(8x2)

Si on GaAs(100)-(4x2)

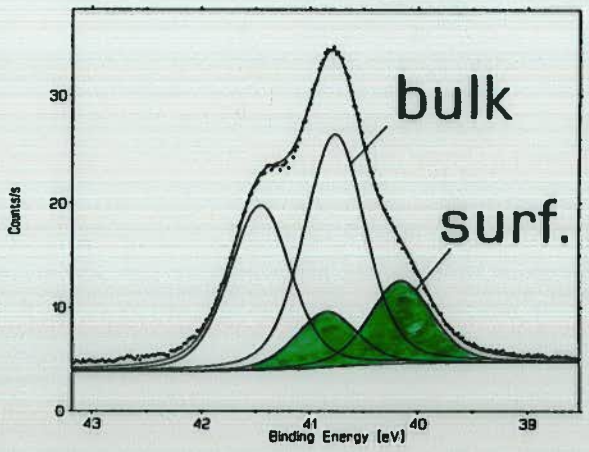
Ga3d



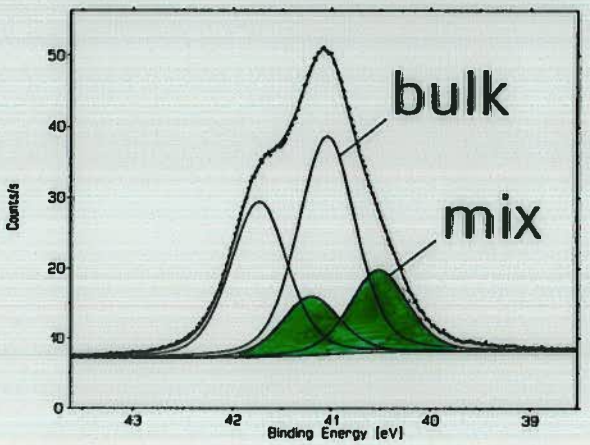




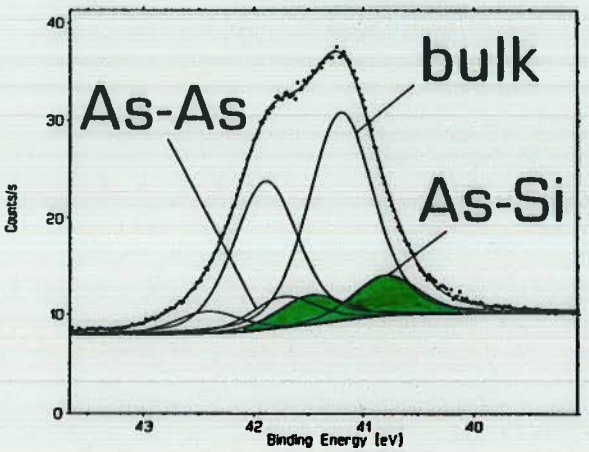
As3d



r=0.3



r=0.6



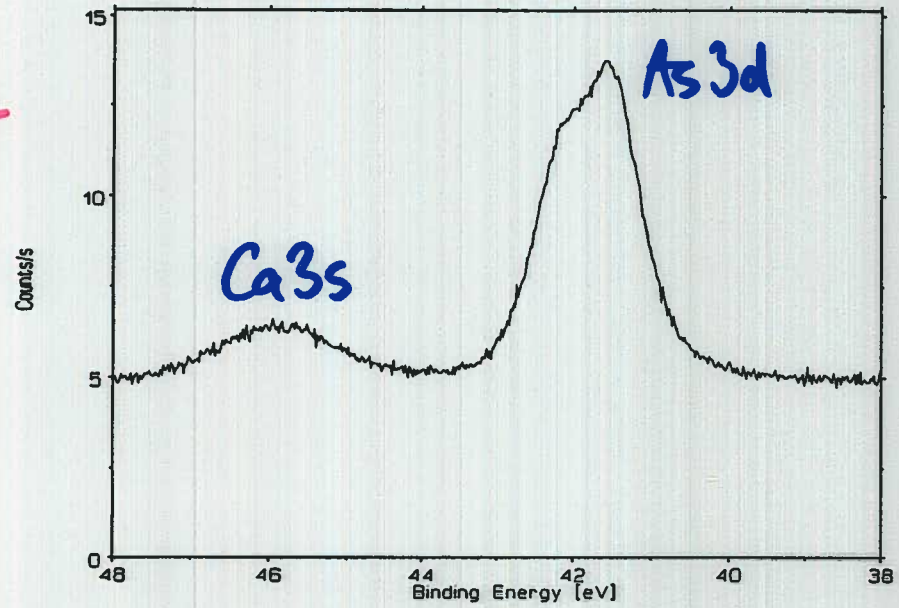
r=1.5

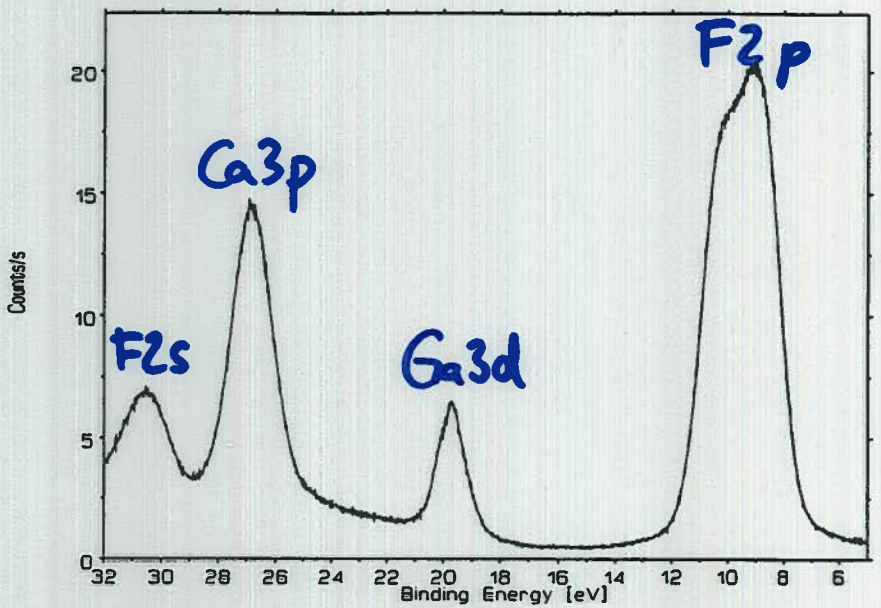
As segregates to the surface !

12 Å CaF_2 / 4 ML Si / GaAs (100) - c(8x2)

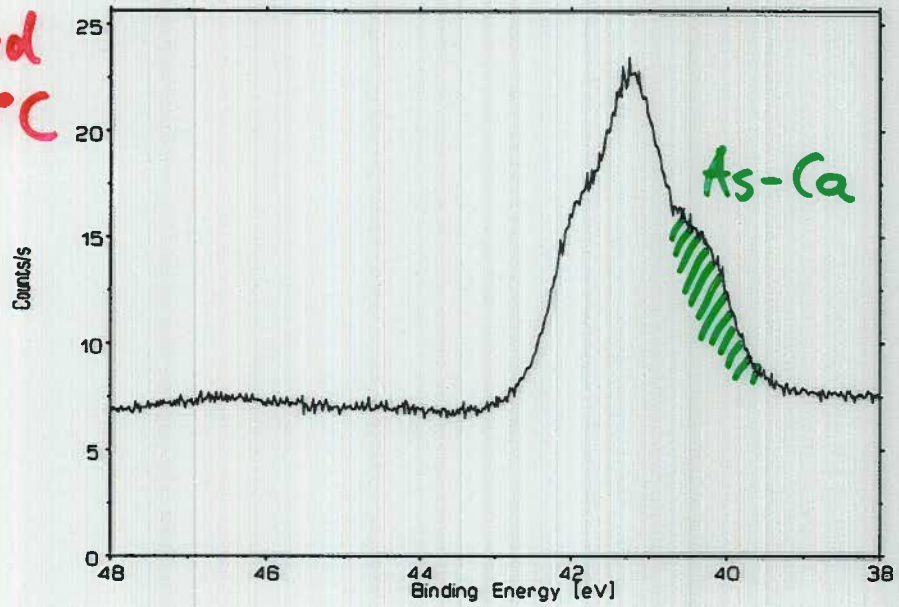
BB = 0.35eV

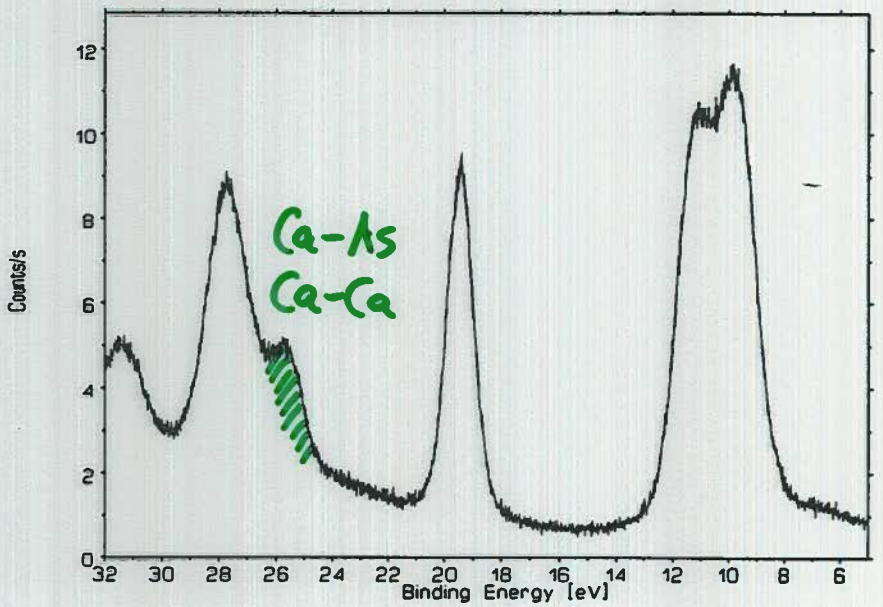
depo. at RT





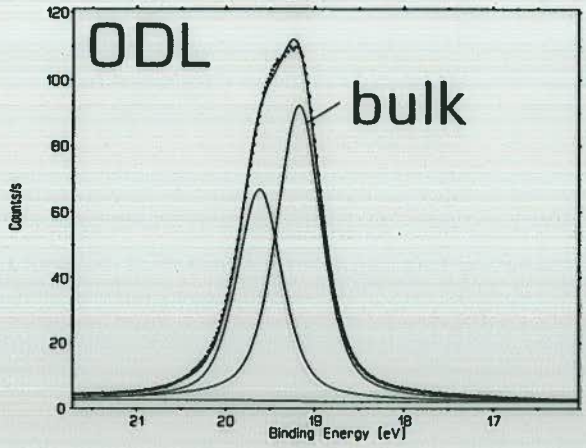
annealed at 620°C

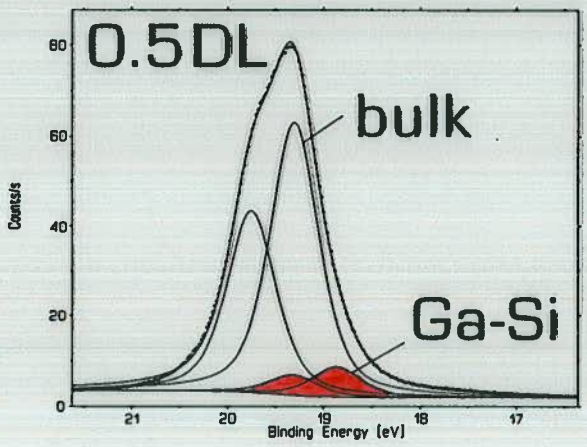


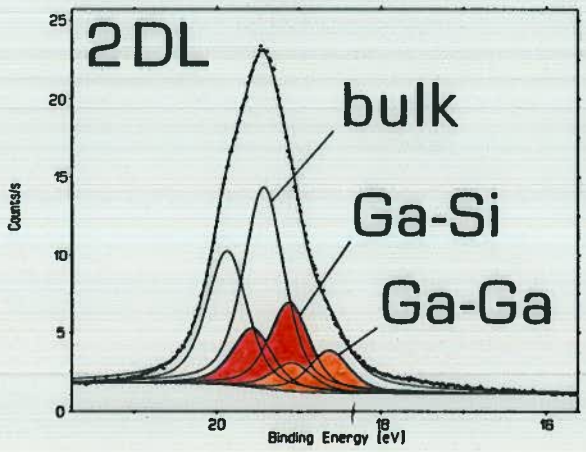


Si on GaAs(111)A-(2x2)

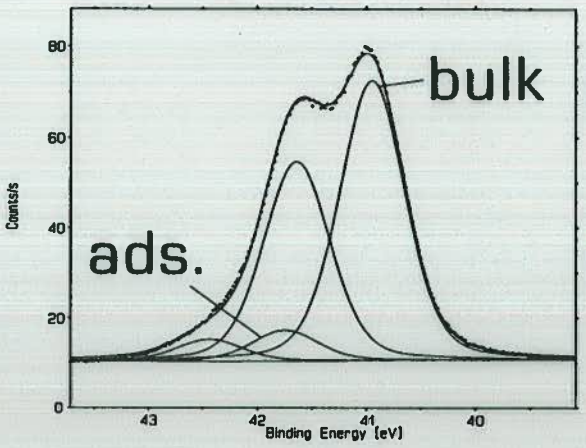
Ga3d





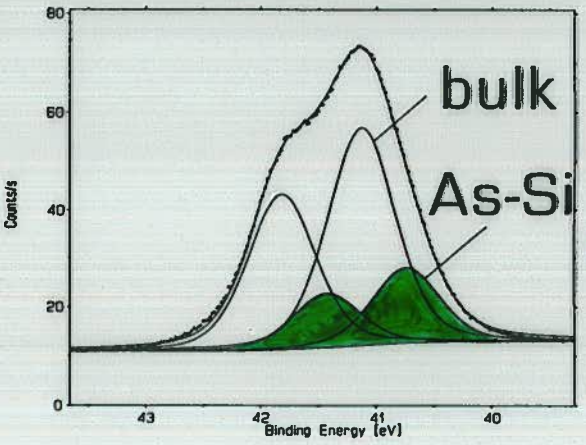


As3d

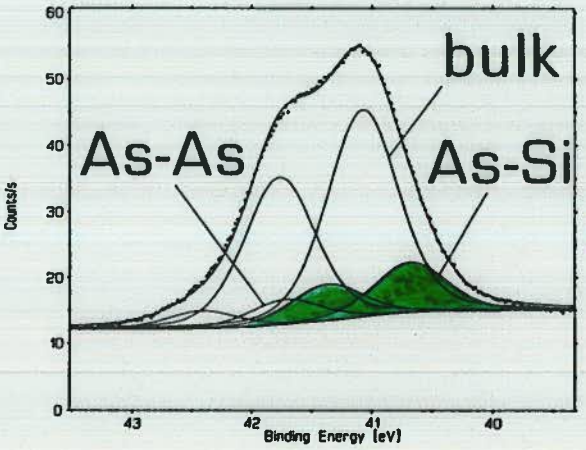


$r = \frac{As}{Ga}$

$r = 0.6$



$r = 0.8$

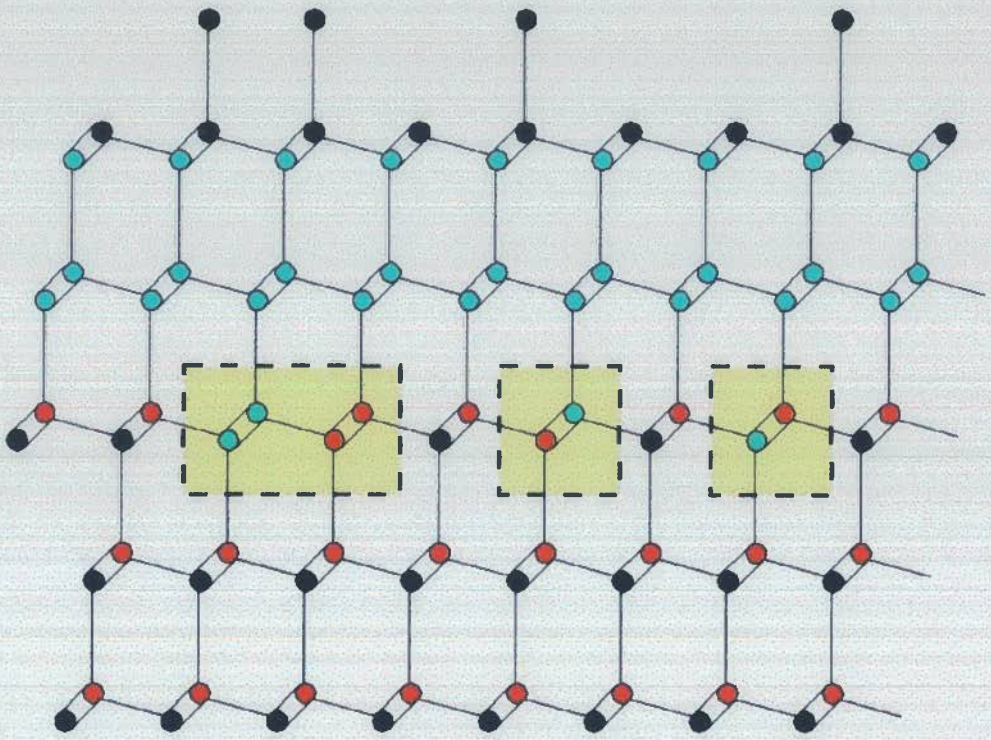


$r = 1.9$

As segregates to the surface!

Heun et al.: PRB 53 (1996) 13 534

Si on GaAs(111)A

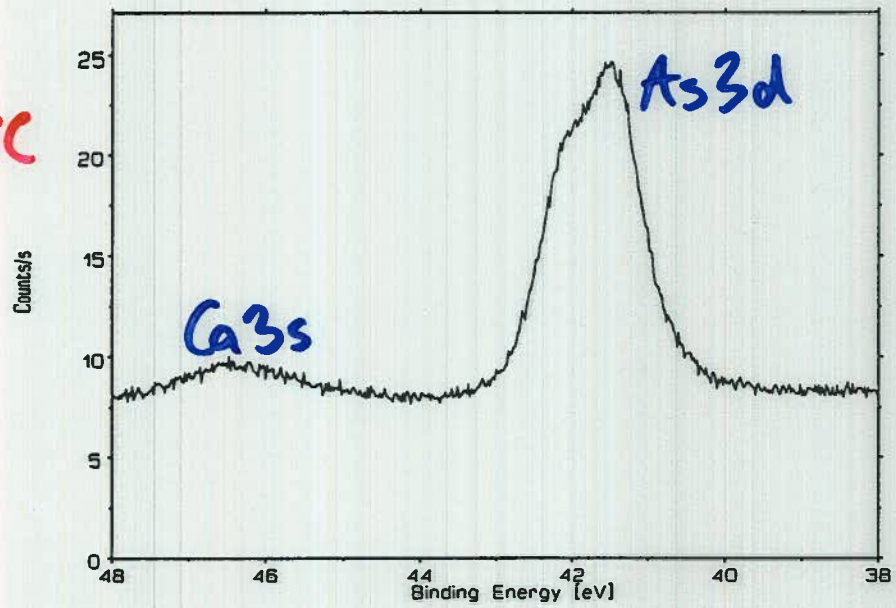


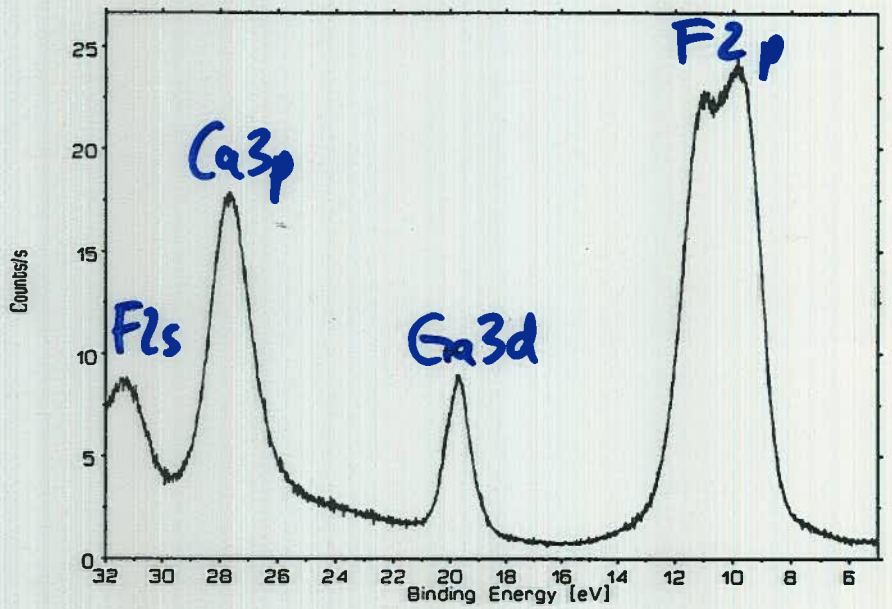
• Ga • As • Si

12 Å CaF_2 / 2DL Si / GaAs (111) A

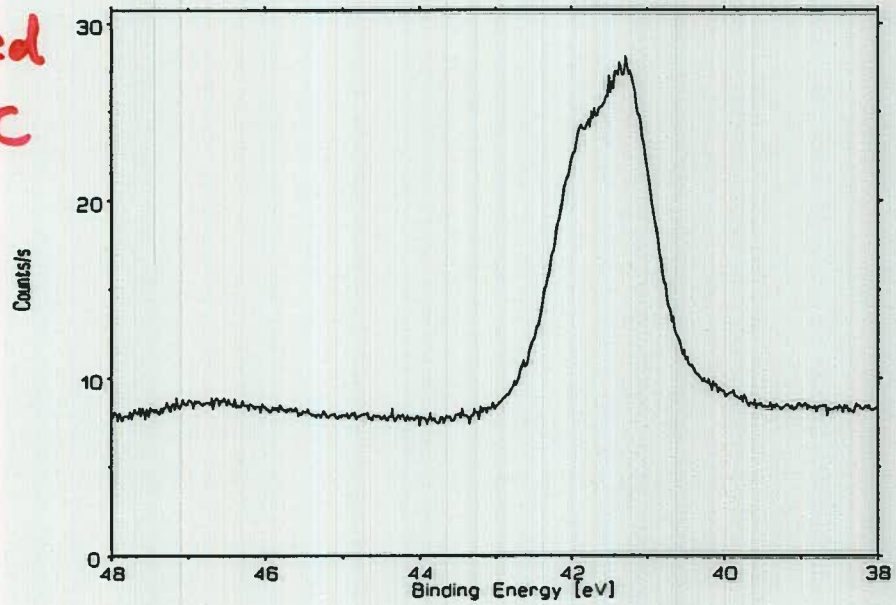
BB = 0.25eV

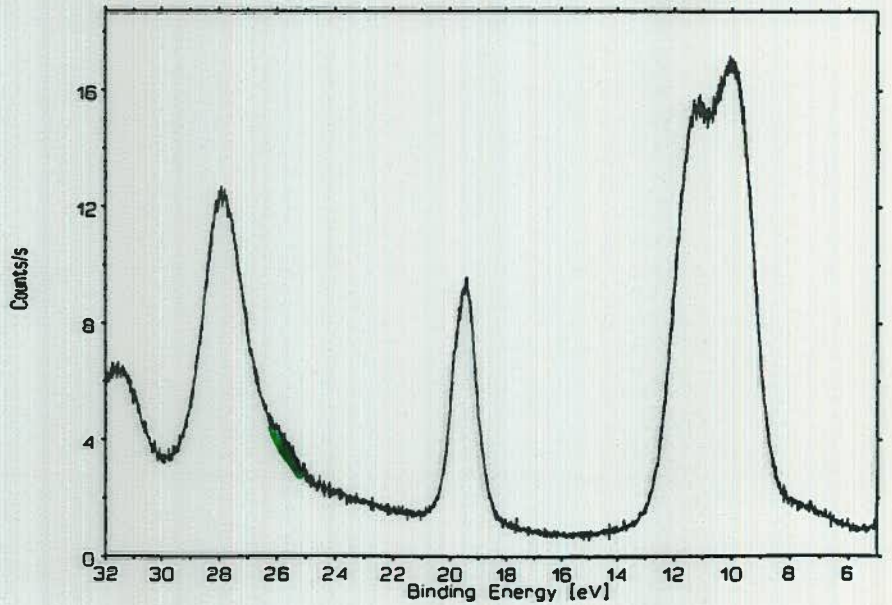
depo. at 450°C





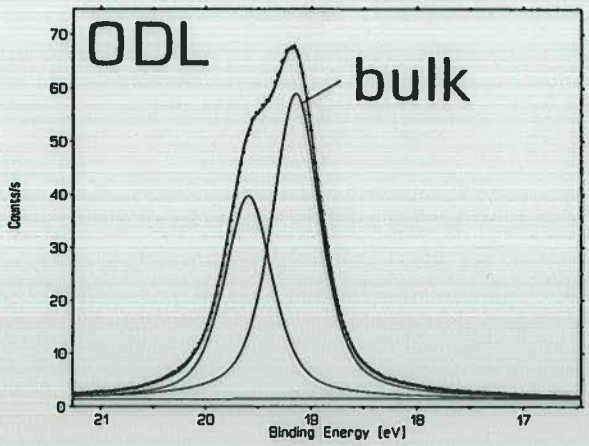
annealed at 620°C

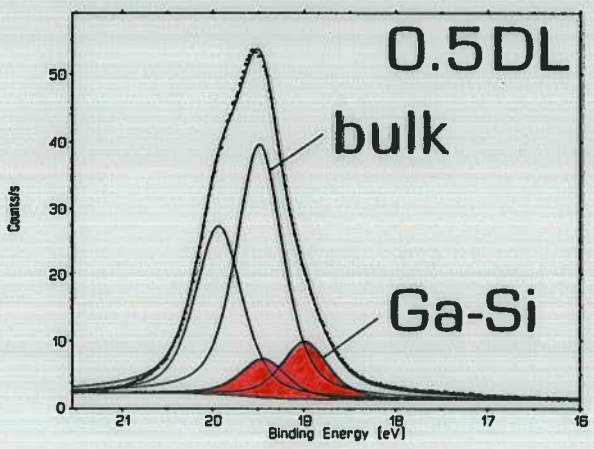


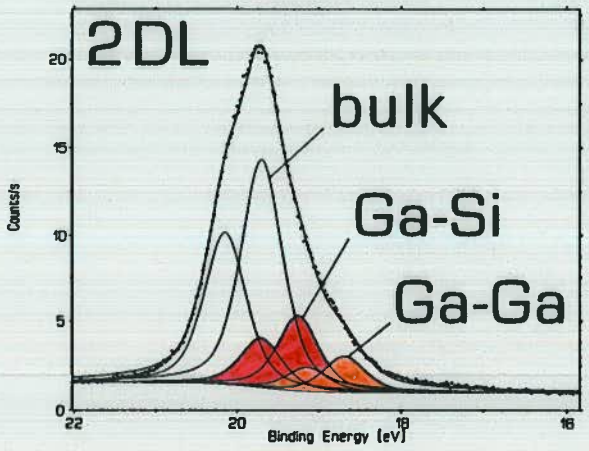


Si on GaAs(111)B-(2x2)

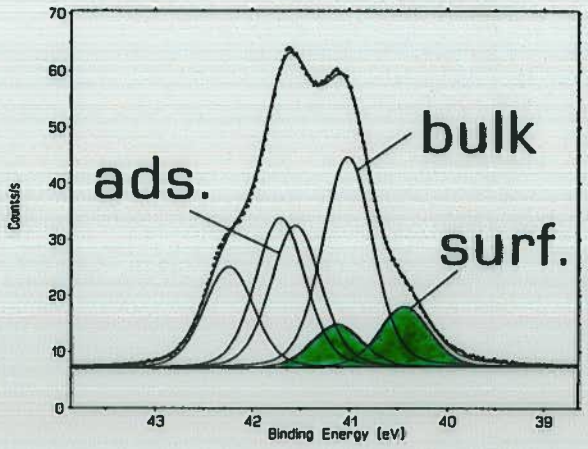
Ga3d





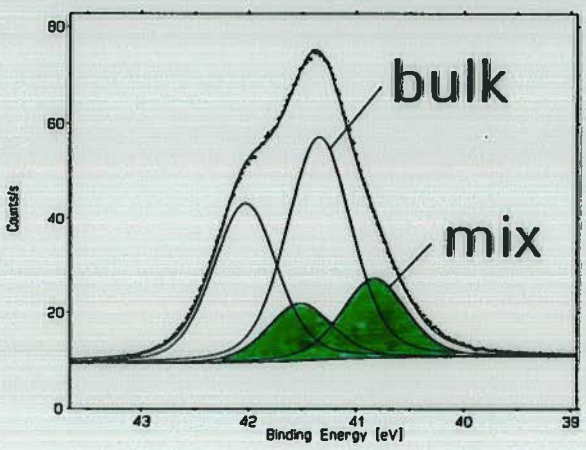


As3d

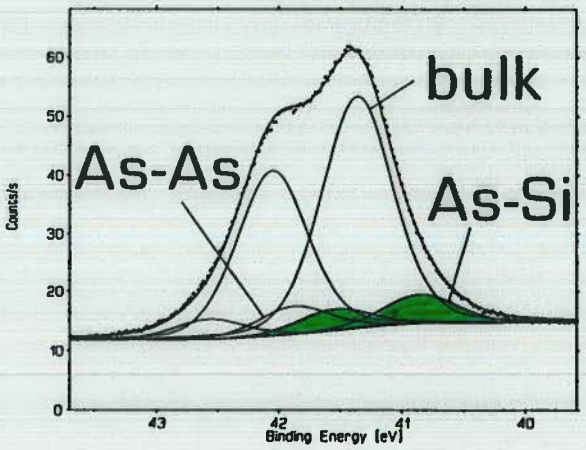


r=0.9

r*=0.6



r=1.3



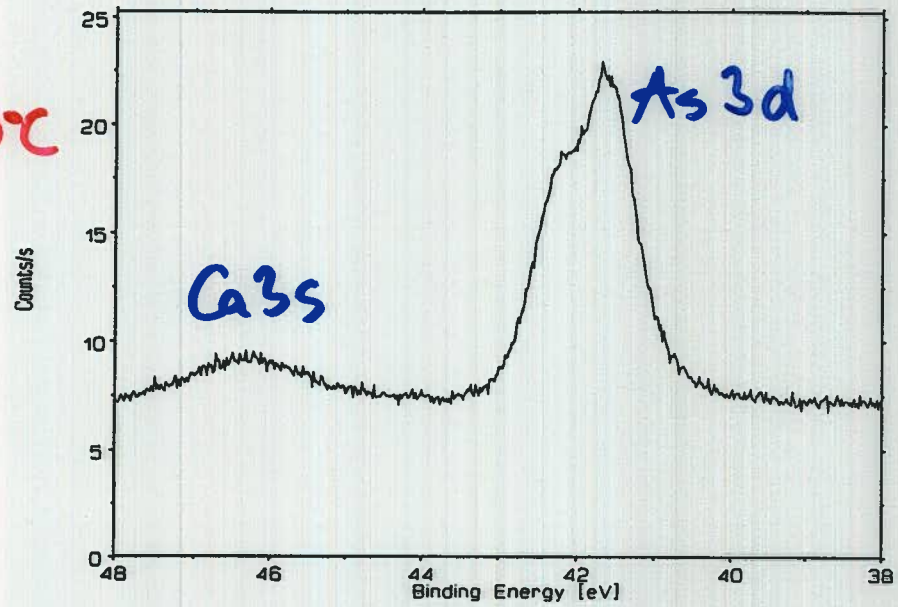
r=2.7

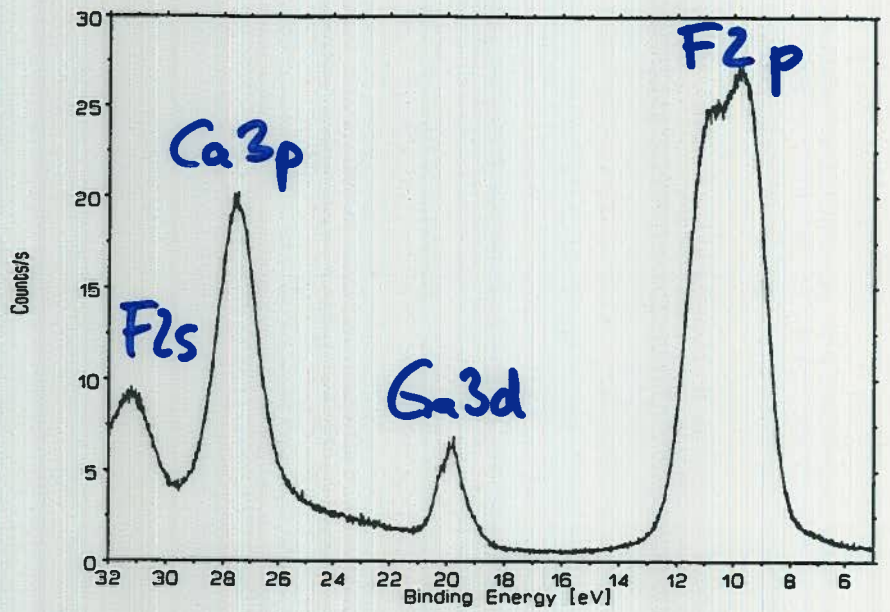
$$r = \frac{I_{As}}{I_{Ga}}$$

As segregates to the surface!

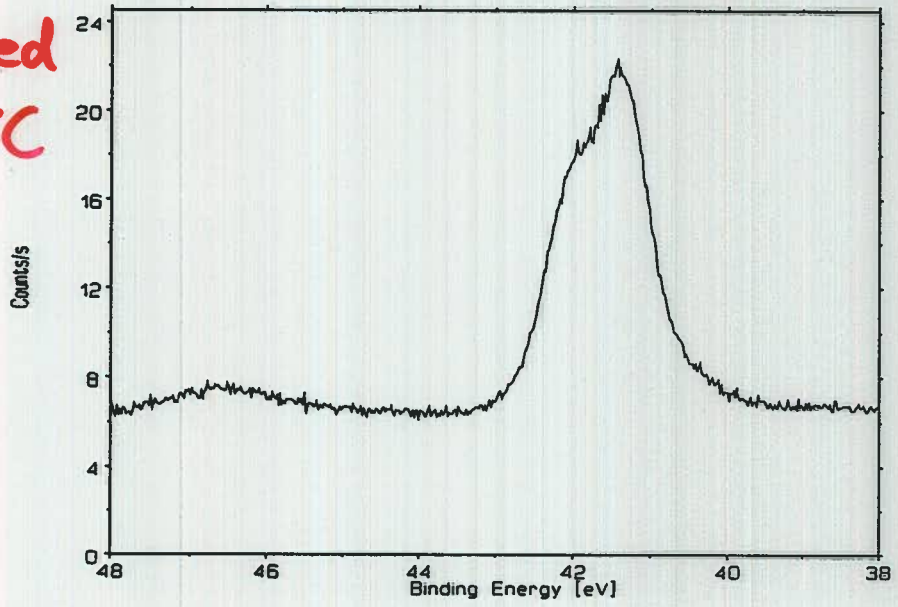
12 Å CaF_2 / 20 L Si / GaAs (111) B

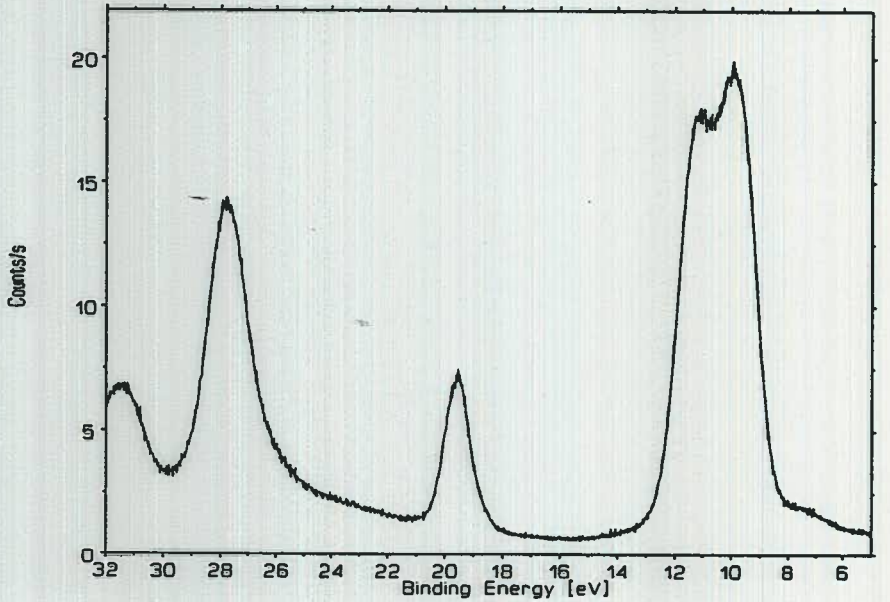
depo. at 450°C





annealed at 620°C





Conclusions

Good epitaxial quality obtained for

Si on GaAs

CaF_2 on Si / GaAs(111)

Si - ICL is a good passivating layer

No interfacial reaction between
CaF_2 and Si / GaAs(111)

Outlook

Fisica della Materia

LABORATORIO TASC - INFM

Istituto Nazionale per la Fisica della Materia

Director: Prof. A. Franciosi

III-V-MBE
Si on GaAs

II-VI-MBE
blue laser

- measurements in Elettra
- collaboration with NTT