Crystal Growth: Physics, Technology and Modeling

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Lecture 8. Liquid phase epitaxy and lateral overgrowth

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http://www.unipress.waw.pl/~stach/cg-2021-22

Liquid phase epitaxy and lateral overgrowth

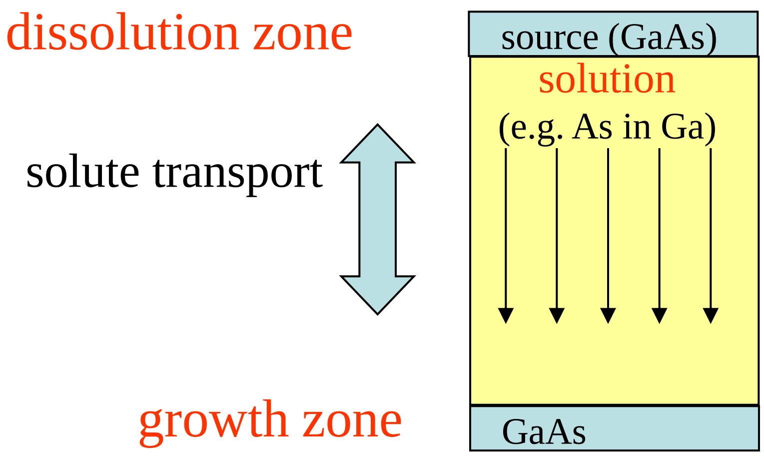
Outline:

- definition + idea of LPE
- history and technical aspects
- solute transport during LPE growth; diffusion, convection
- Liquid Phase Electroepitaxy

- Epitaxial Lateral Overgrowth
- principle and growth control
- filtration of dislocations in ELO
- strain in ELO structures

Liquid Phase Epitaxy - LPE

technique of epitaxial thin films growth *from metallic solution*



advantages of solution growth & epitaxy

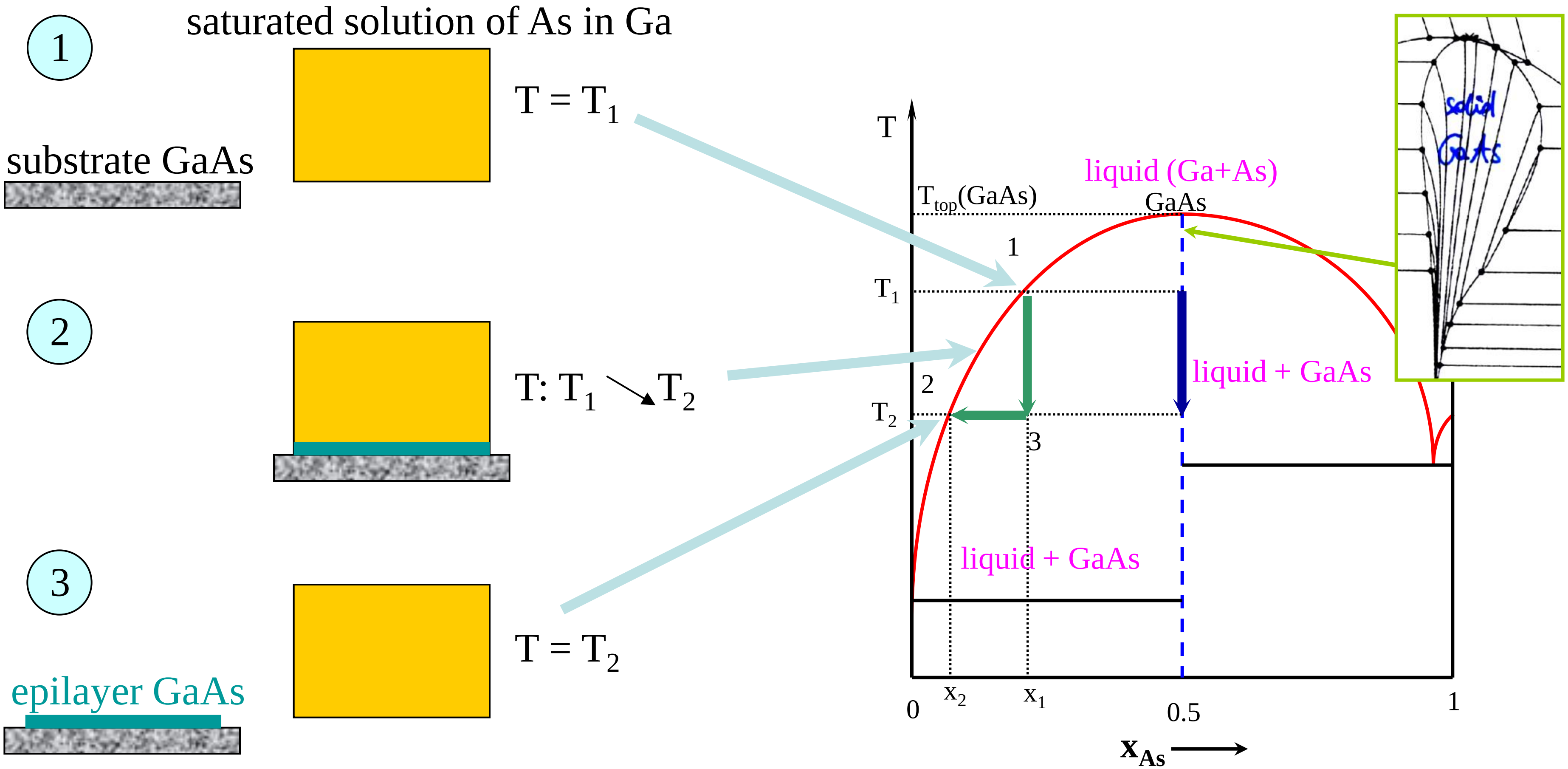
properties of solvent required:

- crystal component (e.g. Ga for GaAs)
  or low solubility in the crystal (Bi, Sn, In, Pb, etc.)
- low melting point
- high solubility of solute @ T_{epi}
- low vapor pressure @ T_{epi}
- high chemical stability
- high purity
- low price ???

Idea of LPE (example: homoepitaxy of GaAs on GaAs substrate)

the Gibbs phase rule: $f_{(\text{degrees of freedom})} = c_{(\text{components})} - p_{(\text{phases})} + 2(p;\,T)$

Ga-As⇔GaAs 2 2 p = const. ⇨ f = 1 (T)



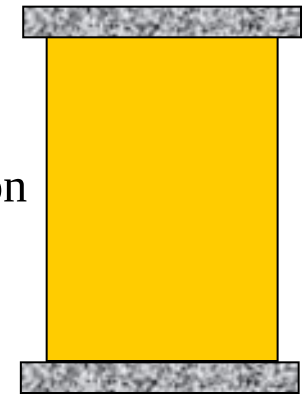
LPE – equilibrium growth method !!!

Idea of LPE (example: homoepitaxy of GaAs on GaAs substrate)

growth in T gradient

GaAs

Ga-As solution



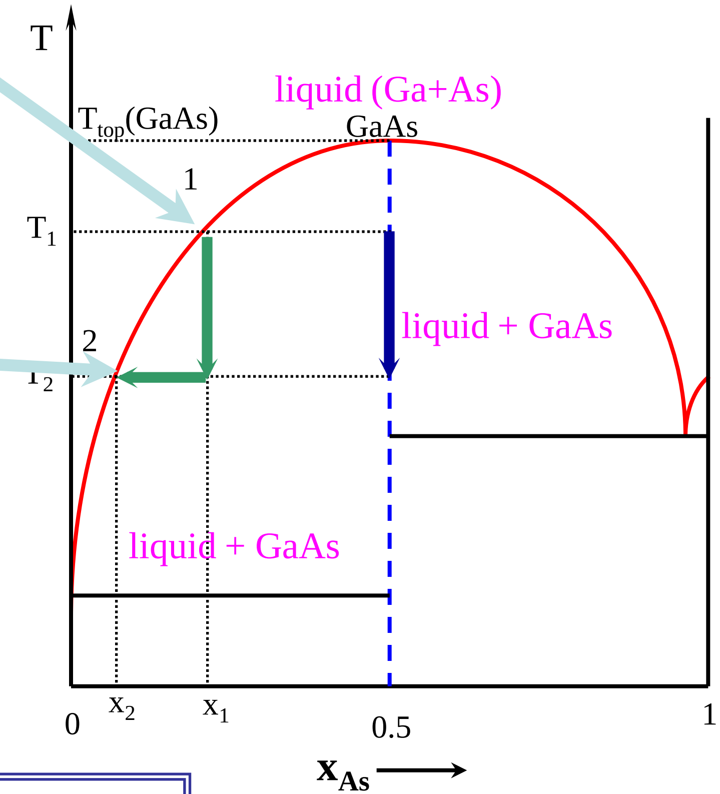
GaAs

$T = T_1$

$C(T_1)$

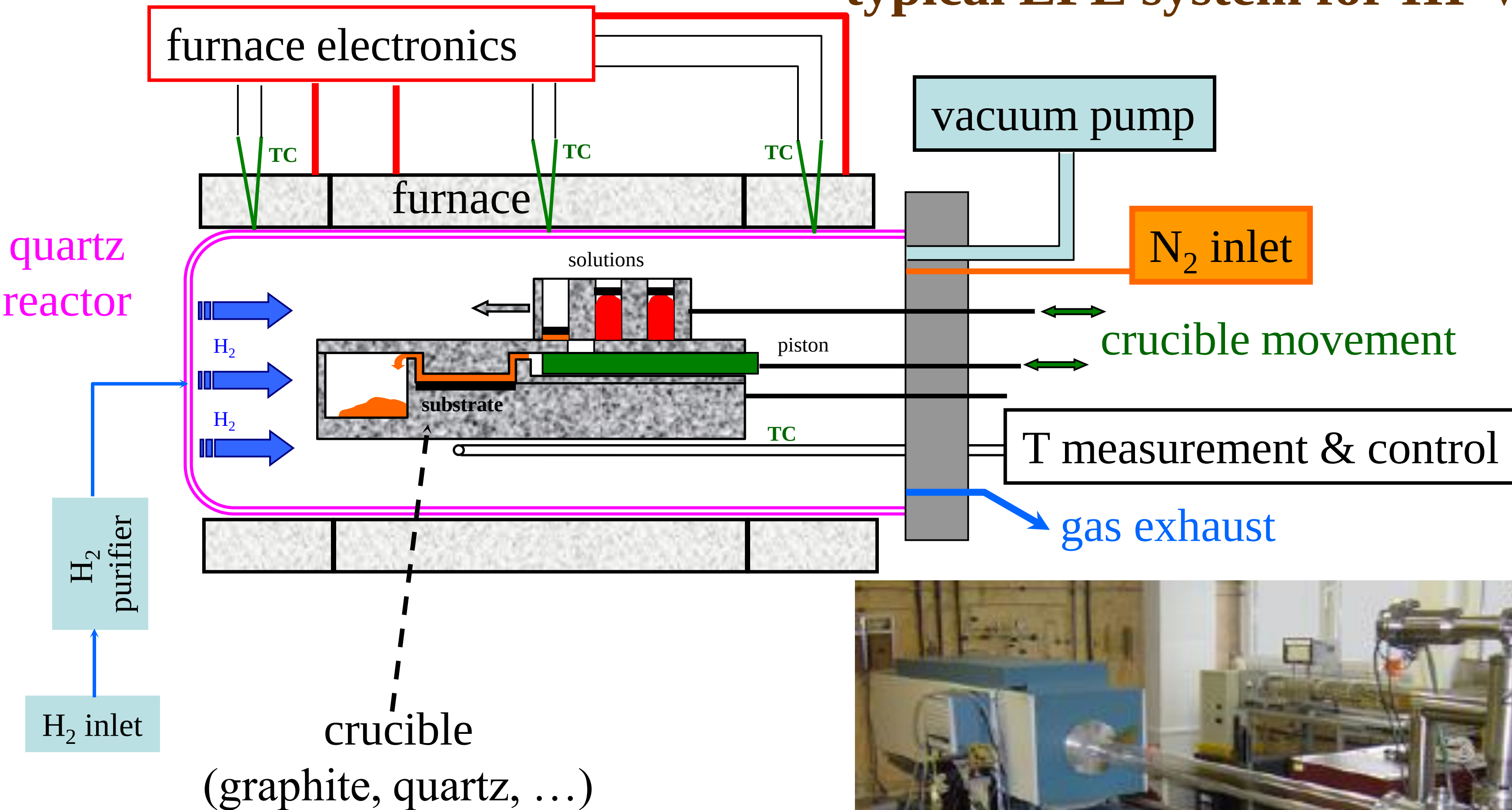
$T = T_2 < T_1$

C(T2) < C(T1)



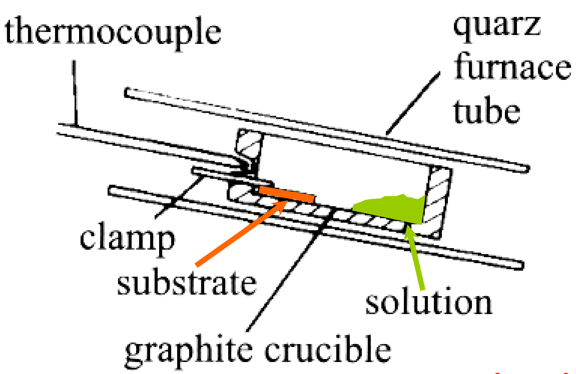
LPE – equilibrium growth method !!!

typical LPE system for III-V's

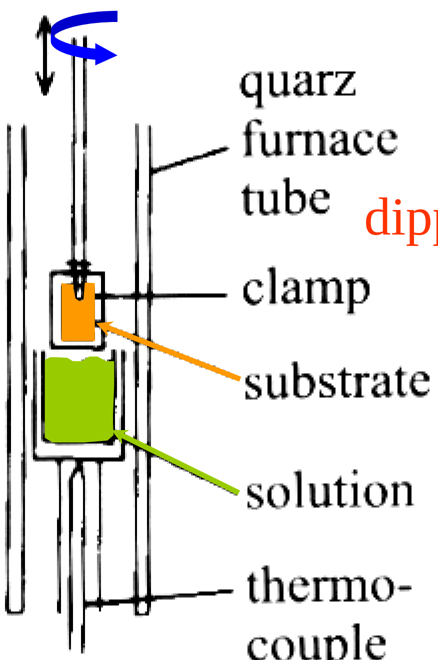


horizontal system
ITE Warszawa

Crucibles in LPE

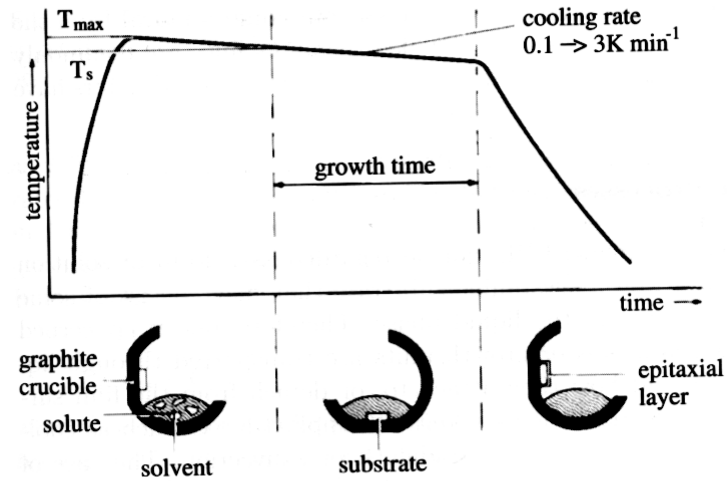


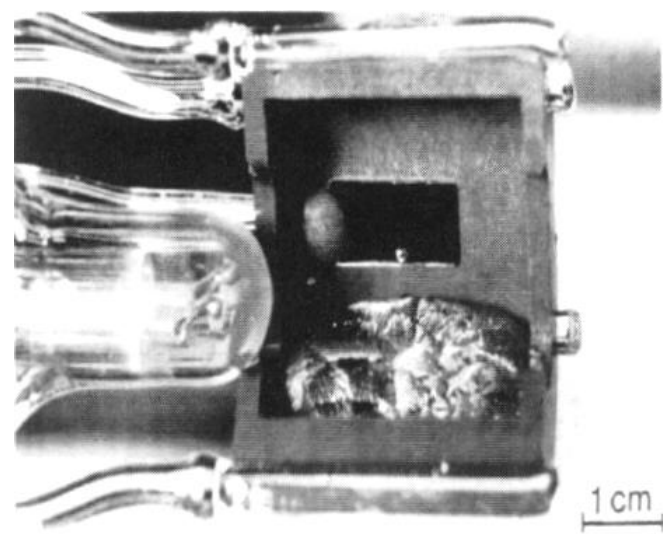
tipping



dipping

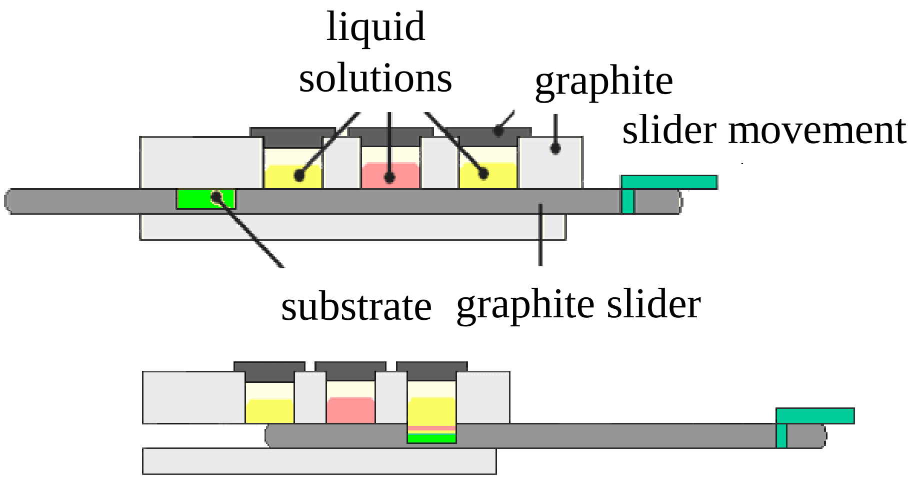
rotation

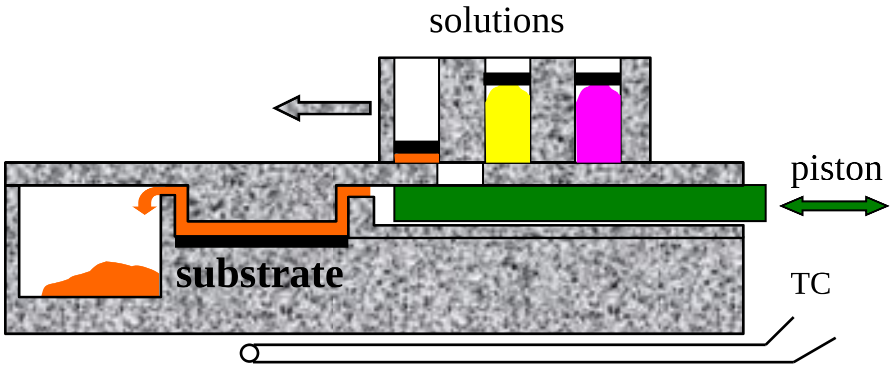


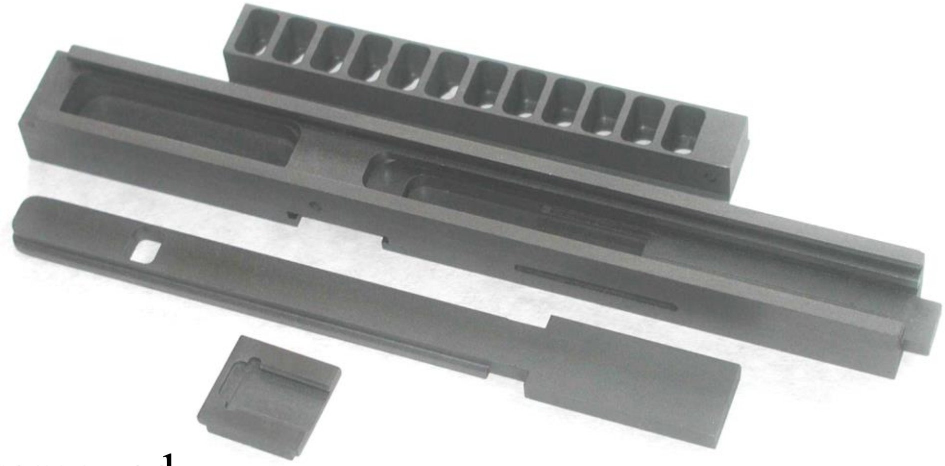


growth of single layers

Crucibles in LPE cont.







advantages:

- growth of multilayer structures
- thin layer of the solution
- „skin” of oxides on the solution surface removed

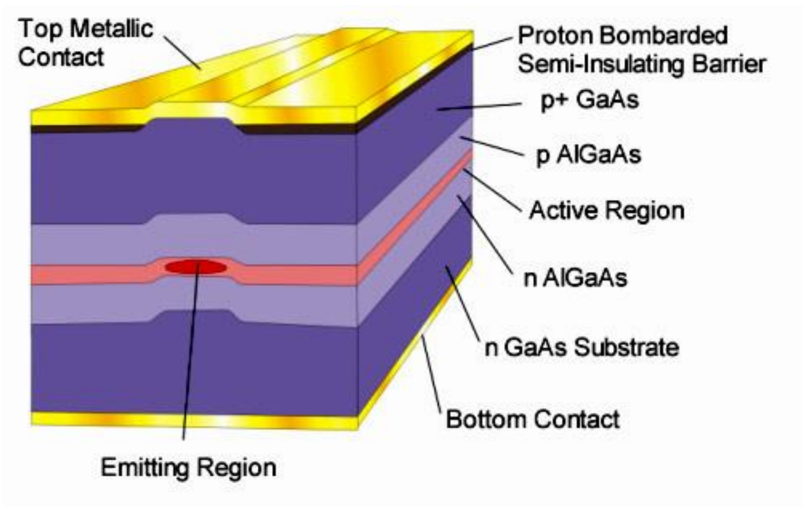
disadvantages:

- blurred (not sharp) interfaces

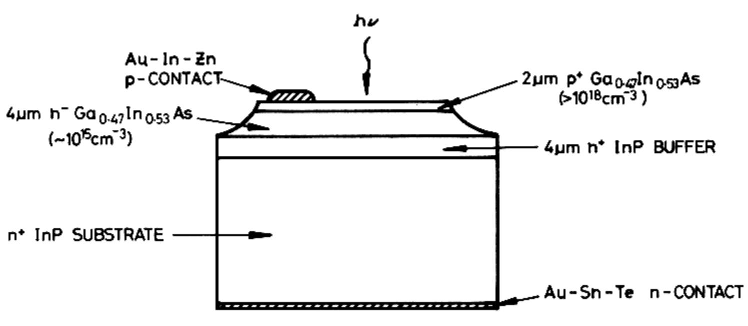
IF PAN

History

H. Nelson: *Epitaxial growth from the liquid state and its application to the fabrication to the fabrication of tunnel and laser diodes* RCA Rev. 24 (1963) 603.



Nobel 2000 - H. Kroemer, J. Kilby, Z. Alfierow
"for developing semiconductor heterostructures used in high-speed- and opto-electronics"



a. HOMOJUNCTION PHOTODIODE

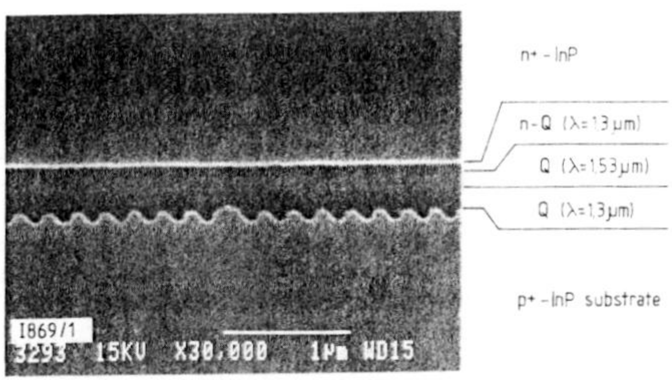
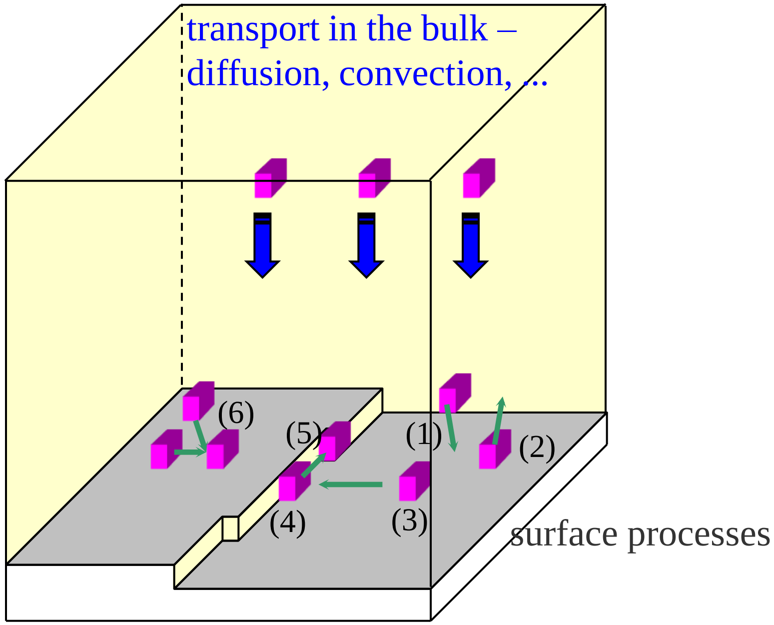


Fig. 14. InGaAsP DFB laser structure grown nearly dissolution-free over a first order grating, after [70]. For details, see text

Why LPE:
- „cheap and easy"
- high purity of layers (impurity segregation)
- selective area growth easy
- broad range of compounds can be grown (As, P, ...)
- „safe" method (as compared to MOVPE)

Growth kinetics



transport of solute in the bulk of solution

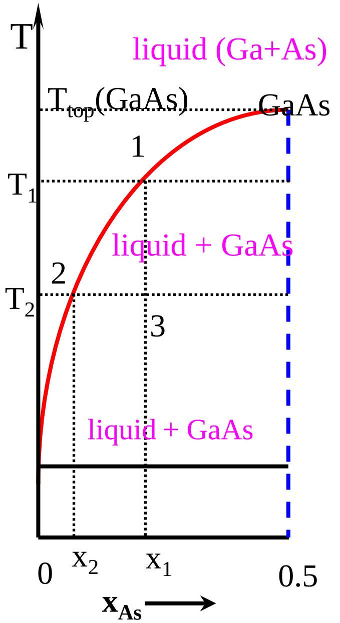
surface processes

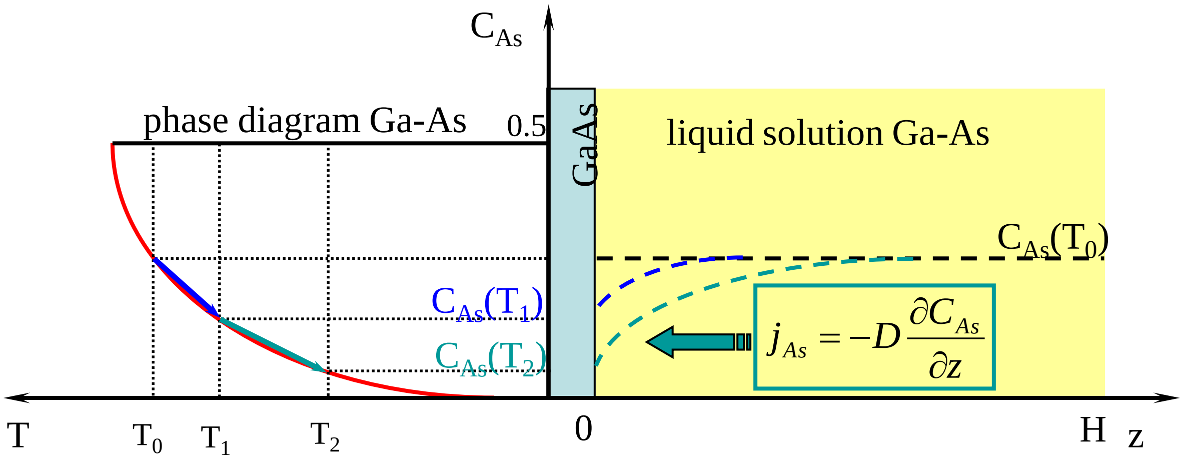
the slower one determines the growth rate

usually

the growth temperature in LPE is so high (surface processes so fast), while the bulk solute transport is slow, that solute transport in the bulk of the solution determines the growth rate

LPE: diffusion controlled growth – example: GaAs growth from Ga-As solution





assumptions:

- fast surface kinetics
- no convective mixing

- low growth rate V_{gr}
- fast heat transport

- no diffusion in solid state

transport: **mass**

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial^2 z} + \cancel{V_{gr}\frac{\partial C}{\partial z}}$$

heat

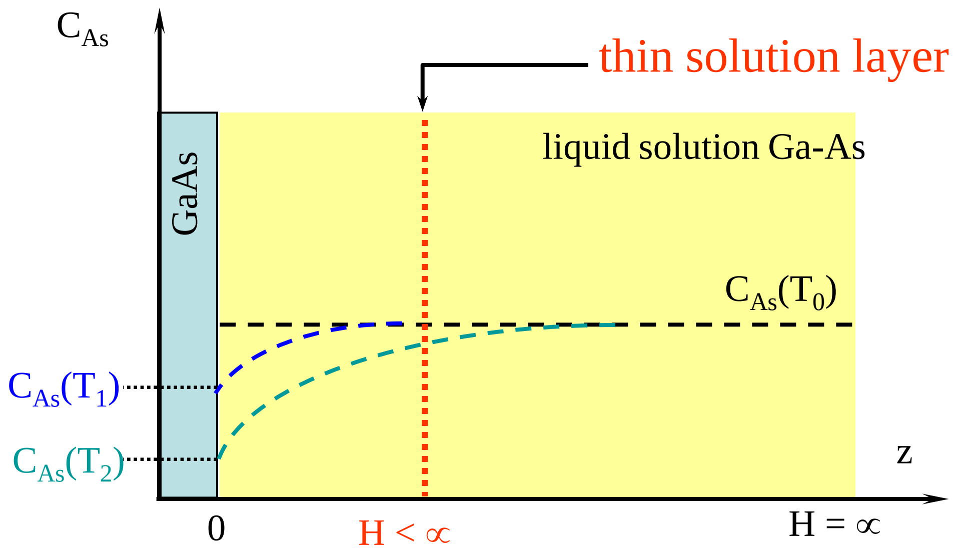
$$\cancel{\frac{\partial T}{\partial t} = k\frac{\partial^2 T}{\partial^2 z} + V_{gr}\frac{\partial T}{\partial z}}$$

mass flux continuity condition

$$V_{gr}\left(C_{s,z=0} - C_{l,z=0}\right) = D_l\frac{\partial C_l}{\partial z}\Big|(z=0) - \cancel{Ds\frac{\partial C_s}{\partial z}\Big|(z=0)}$$

+ initial and boundary conditions
(which depend on LPE version, e.g. T(t))

LPE: diffusion controlled growth – example: GaAs growth from Ga-As solution



equations $\boxed{\dfrac{\partial C}{\partial t} = D\dfrac{\partial^2 C}{\partial^2 z}}$ $\boxed{V_{gr}\left(C_{s,z=0} - C_{l,z=0}\right) = D_l \dfrac{\partial C_l}{\partial z}\Big|(z=0)}$

infinite solution $H = \infty \Leftrightarrow H >> \sqrt{D_l t}$

$\text{Ga - As}: T = 800^o C \quad D_l \approx 4 \cdot 10^{-5}\ \text{cm}^2/\text{s}$

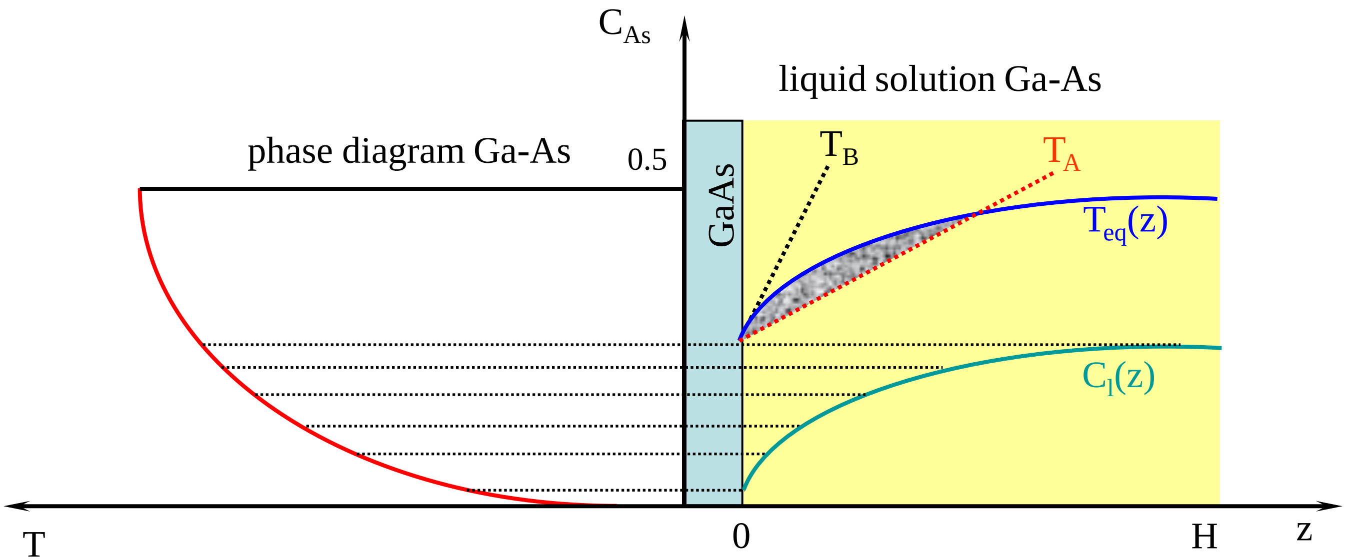
$t = 30\ \text{min} \quad \sqrt{Dt} = 2.6\ \text{mm}$

initial and boundary conditions $\boxed{C_l(z=0,t) = C_{eq}(T(t))}$ $\boxed{\dfrac{\partial C_l}{\partial z}(z \to \infty, t) = 0}$

equilibrium at the solid/liquid interface

LPE version

LPE: constitutional supersaturation



theory:

increase grad T at the interface

(T_B instead of T_A)

Udayashankar et al., Bull. Mater. Sci 26 *(2003) 685*

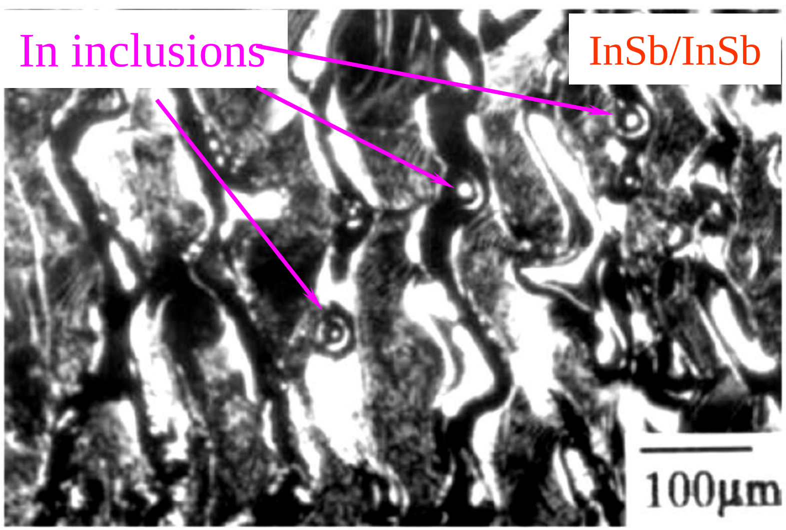
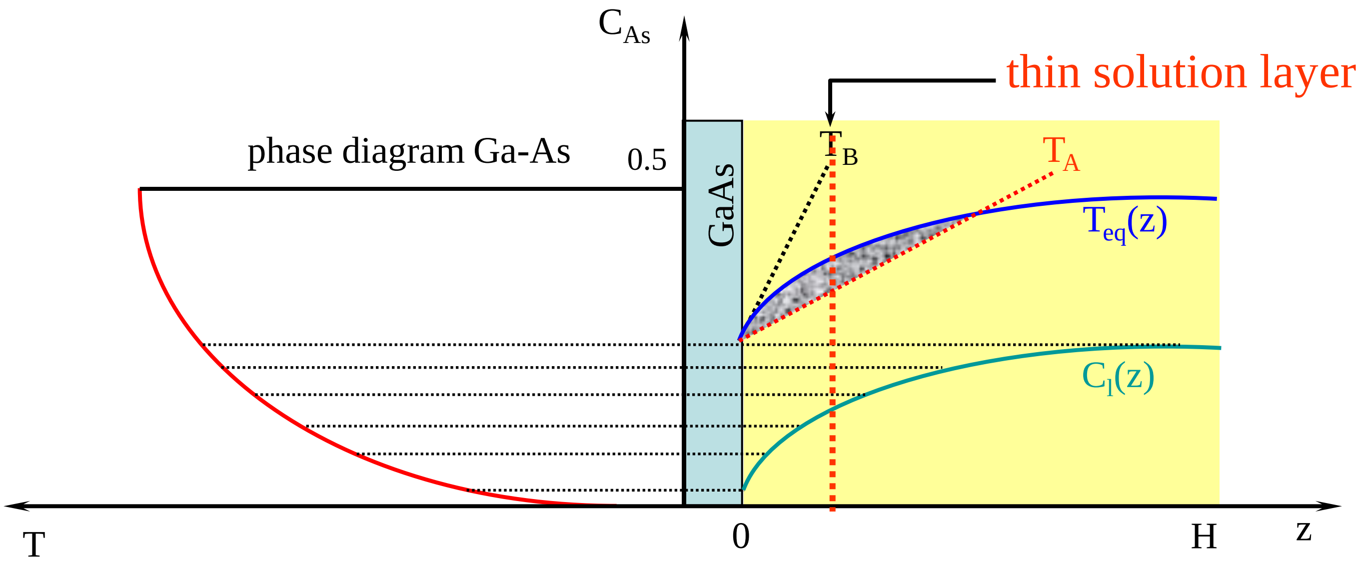


Figure 3. Film showing various surface features like ridges, valleys, inclusions, etc.

LPE: constitutional supersaturation



Udayashankar et al., Bull. Mater. Sci 26 *(2003) 685*

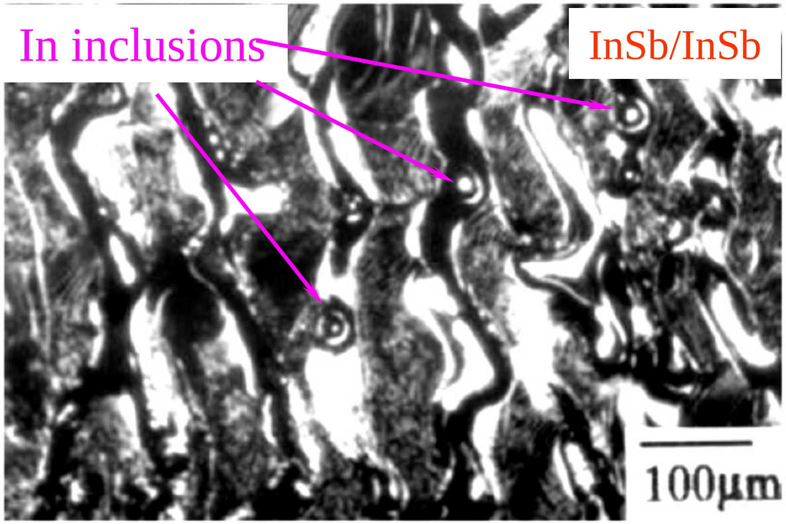


Figure 3. Film showing various surface features like ridges, valleys, inclusions, etc.

theory:

increase grad T at the interface (T_B instead of T_A)

practice:

decrease concentration gradient

- thinner solution layer
- lower the growth rate

LPE: natural convection

natural convection

$$\rho = \rho(T, C) \text{ + gravity}$$

convection thermal solutal

$$\frac{\partial \rho}{\partial T} < 0 \qquad \frac{\partial \rho}{\partial C} \ ???$$

assumptions:

- no external mixing
- vertical substrate
- T(x, y, z) = const.

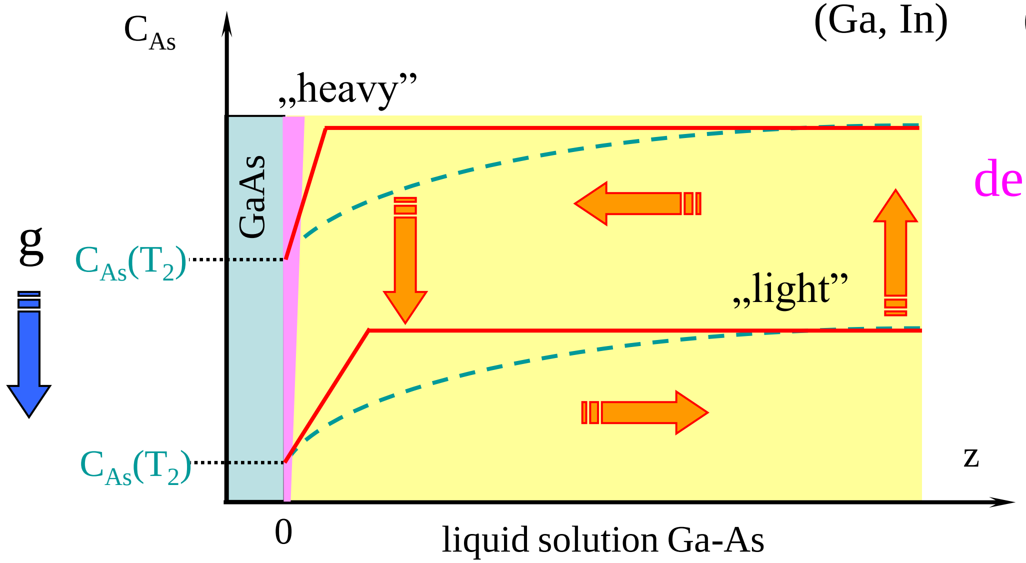
solutal convection only

typical III-V solutions

$\rho_{solvent} > \rho_{solute}$

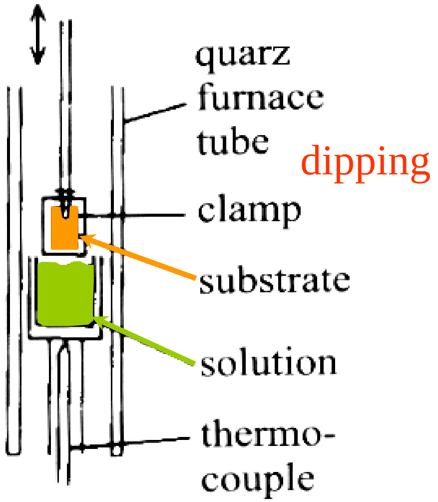
(Ga, In) (As, P)

$$\boxed{\frac{\partial \rho}{\partial C} < 0}$$



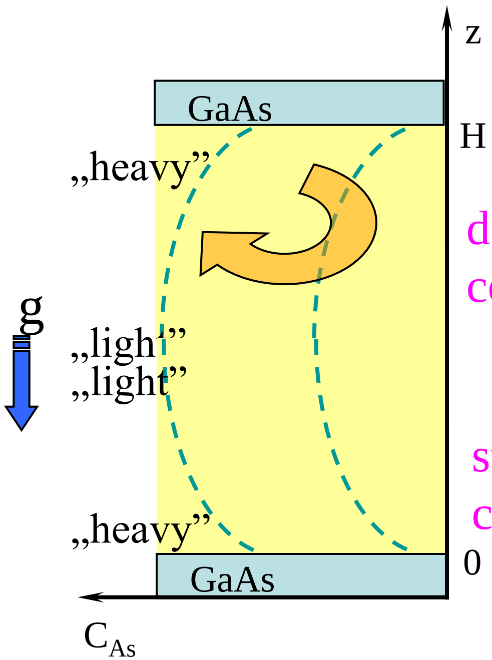
destabilizing solute distribution (As)

epilayer thickness gradient



LPE: natural convection cont.

S. Krukowski's lecture



destabilizing solute (As) concentration distribution

stabilizing solute (As) concentration distribution

if the Rayleigh's number is low Ra (<1000)

diffusion dominates

usually both gradT and gradC exist

$$Ra_C = g \cdot \Delta C \cdot \beta \cdot H^3 / D\nu < 1000$$

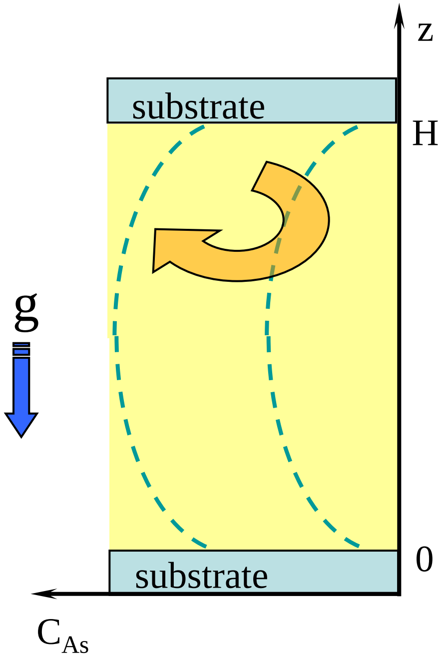
$$Ra_T = g \cdot \Delta T \cdot \alpha \cdot H^3 / \kappa\nu < 1000$$

- κ >> D – small ΔC leads to convective flow
- solutal convection >> thermal convection
- Ra ~ H^3 - solution layer thickness !!!

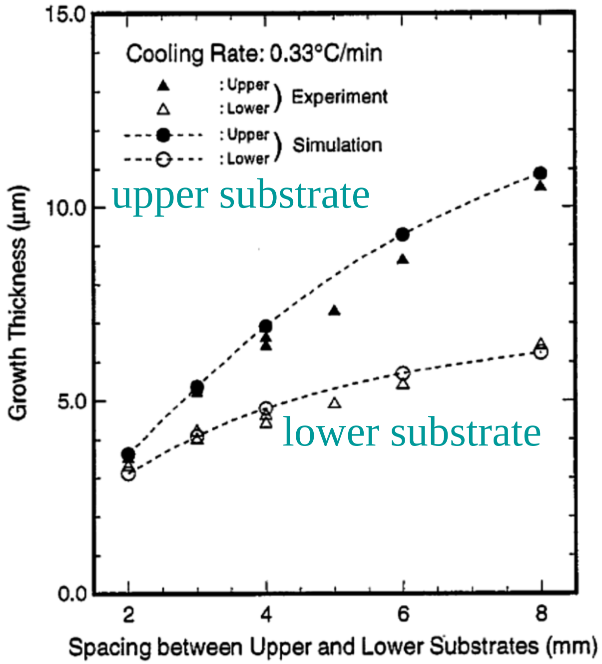
Tiller JCG 2 (1968) 69: no thermal convection if H < 5 mm
no solutal convection if H < 2 mm

LPE from thin solution layer !!!

LPE: natural convection cont.

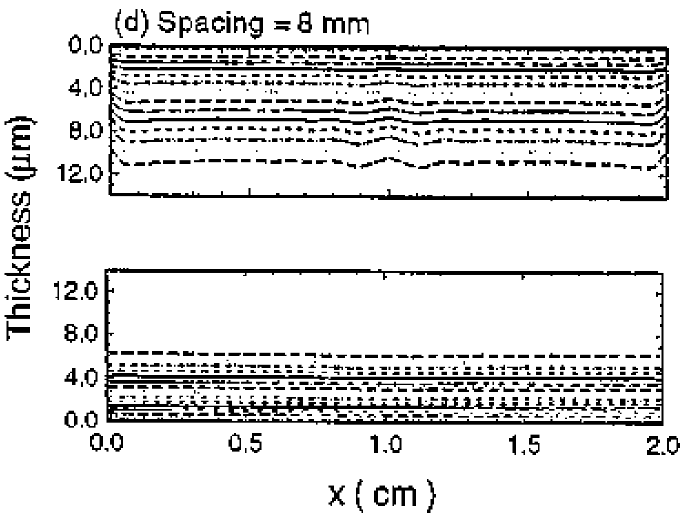


Kimura et al. JCG 167 (1996) 516



LPE of Si from Sn solution

simulation + exp.

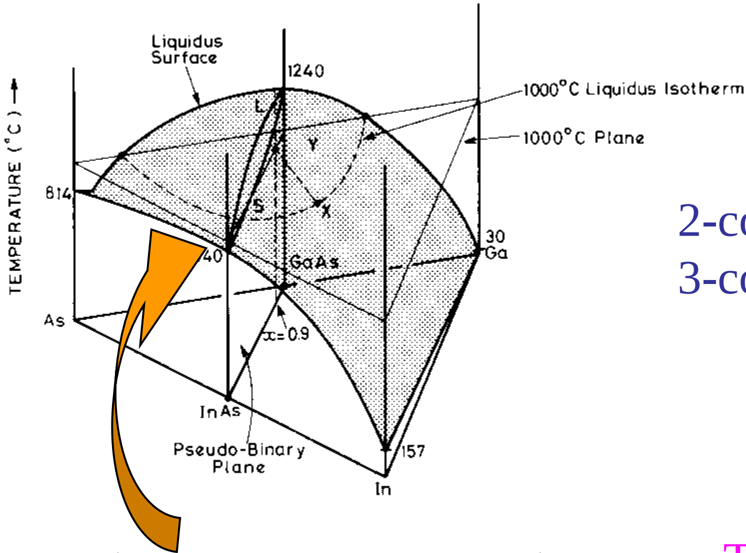


for thin solutions growth
on both substrates similar

LPE of multicomponent systems (example: GaAlAs on GaAs)

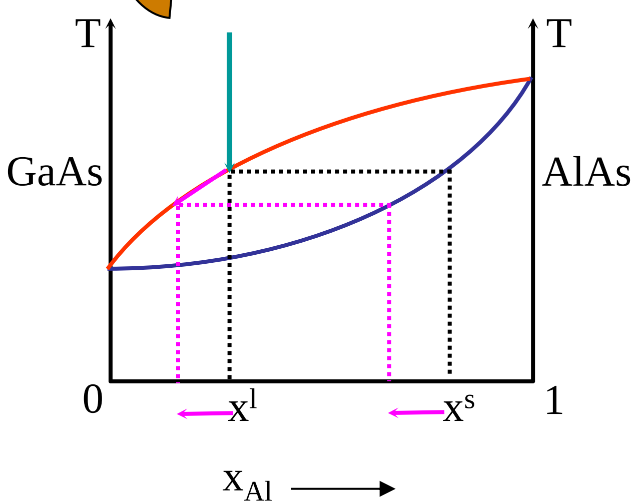
the Gibbs phase rule: $f_{\text{(degrees of freedom)}} = c_{\text{(components)}} - p_{\text{(phases)}} + 2(p; T)$

e.g. Ga-Al-As ⇔ $Ga_{1-x}Al_xAs$ 3 2 p = const. ⇨ f = 2 (T, x)



2-component system: composition of epilayer fixed

3-component system: composition of epilayer (x) - variable



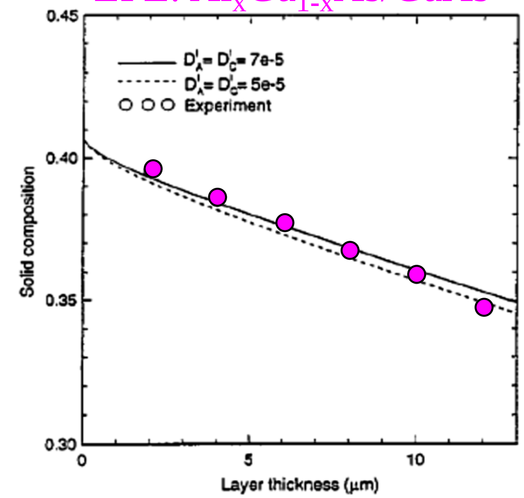
T↓ - grad x^s

T = const.

⇩

x^s = const.

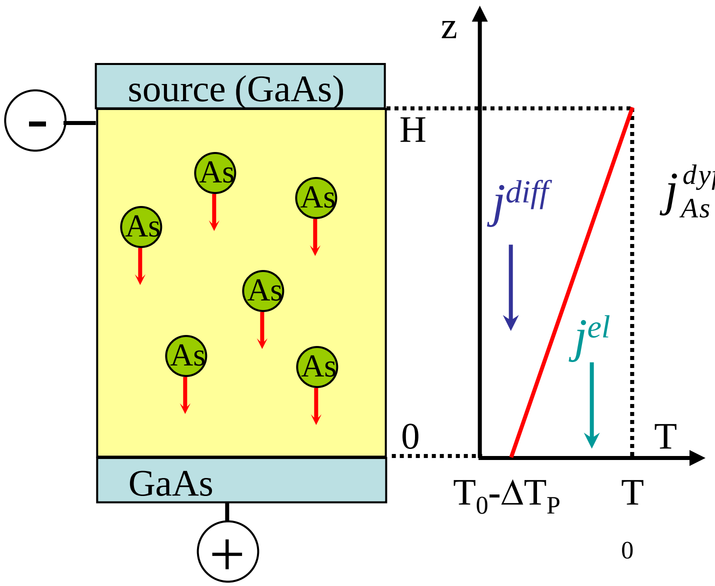
LPE: $Al_xGa_{1-x}As/GaAs$



LPE growth of compositionally uniform AlGaAs layers challenging

Liquid phase electroepitaxy (LPEE)

T_0 = const. + DC current flow through the solid/liquid interface



Peltier effect

$$j_{As}^{dyf} = D \cdot \frac{C(T_0) - C(T_0 - \Delta T_P)}{H}$$

$$= D \cdot {dC}/{dT} \cdot {\Delta T_P}/{H}$$

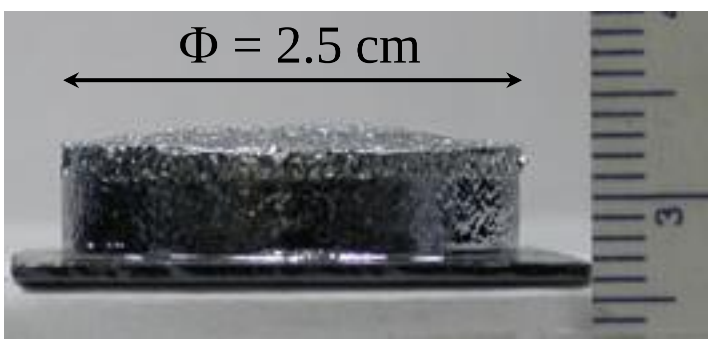
electrotransport

„electron wind” effect

$$j_{As}^{el} = \mu \cdot E \cdot C(T_0)$$

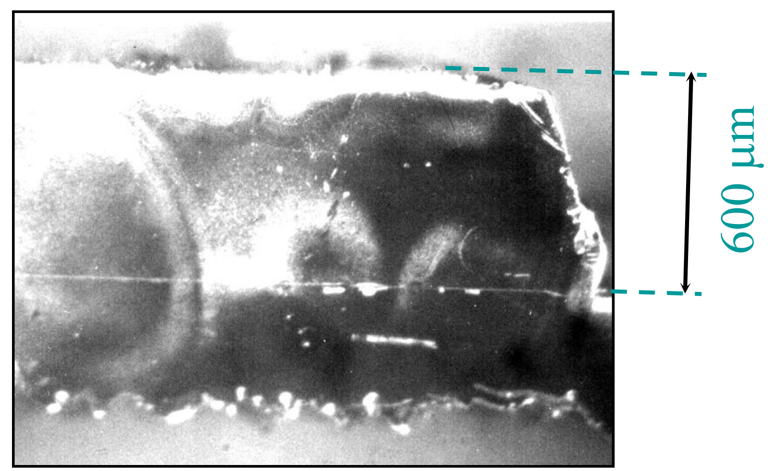
$$= \mu \cdot \sigma \cdot j_e \cdot C(T_0)$$

$$\boxed{V_{gr} \propto \textit{electric current density}}$$



LPEE InGaAs/GaAs

S. Dost, Univ.Victoria, BC, Canada



LPEE AlGaSb/GaSb

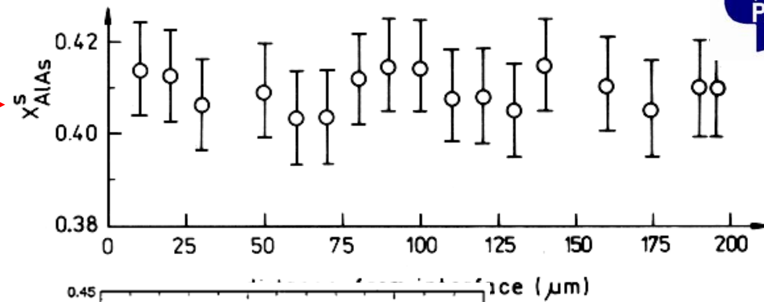
Z.R. Zytkiewicz, IF PAN

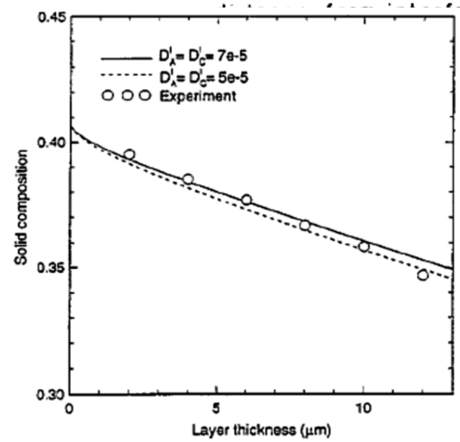
LPEE - advantages

- compositional uniformity
- *in situ* monitoring
- time markers
- simultaneous growth of many crystals
- „easier" V_{gr} control ~ current density
- surface stability

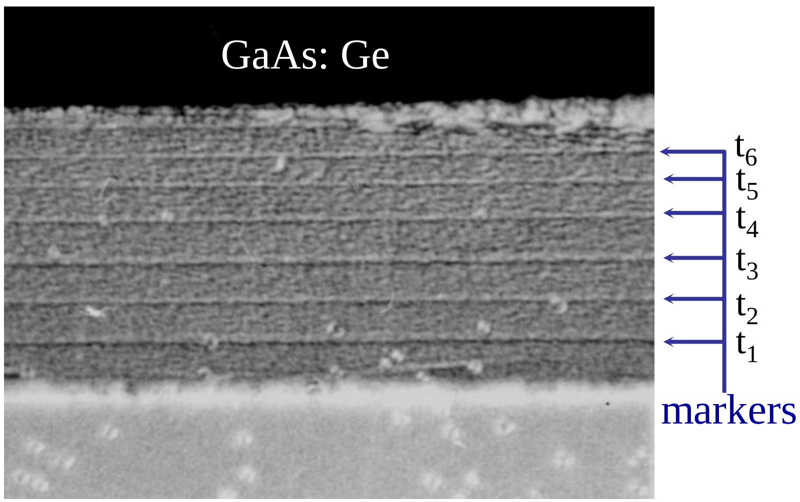
T = const.

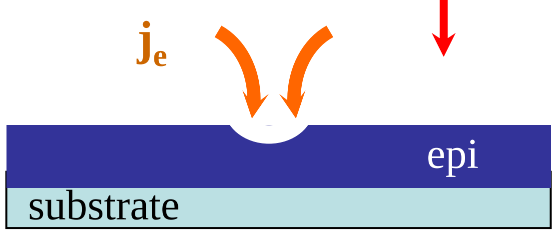
LPEE $Al_xGa_{1-x}As/GaAs$

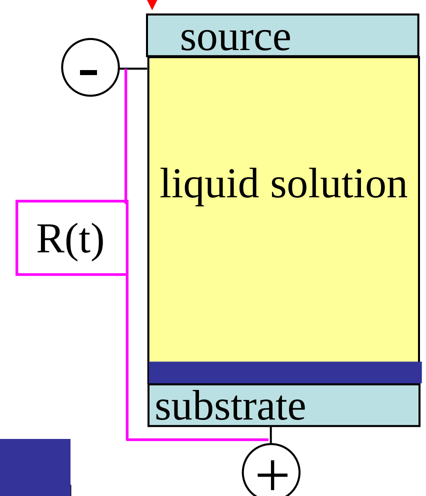


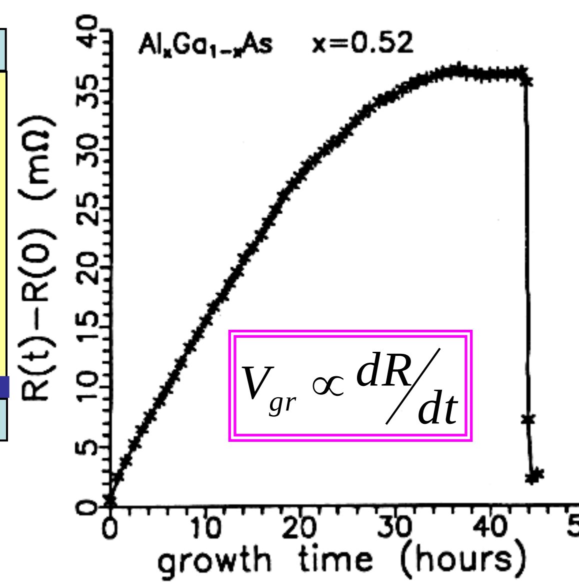


LPE $Al_xGa_{1-x}As/GaAs$







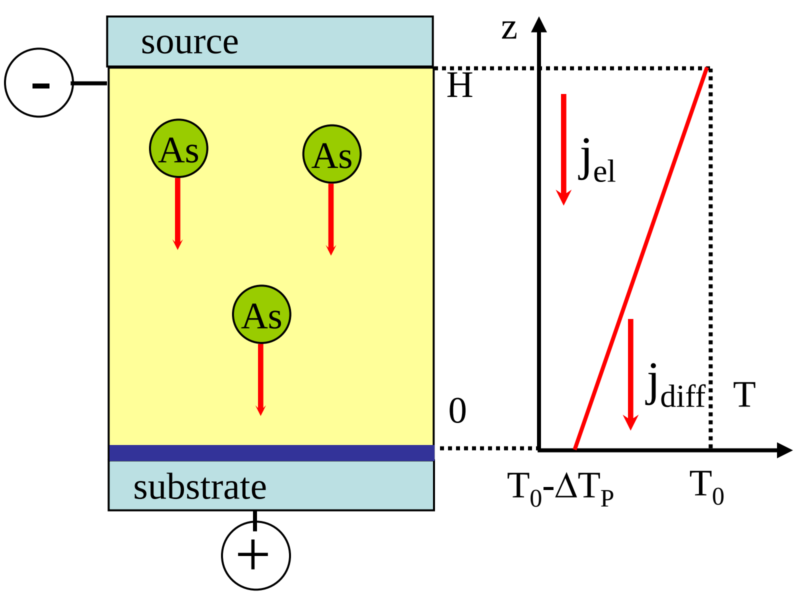


LPEE - disadvantages

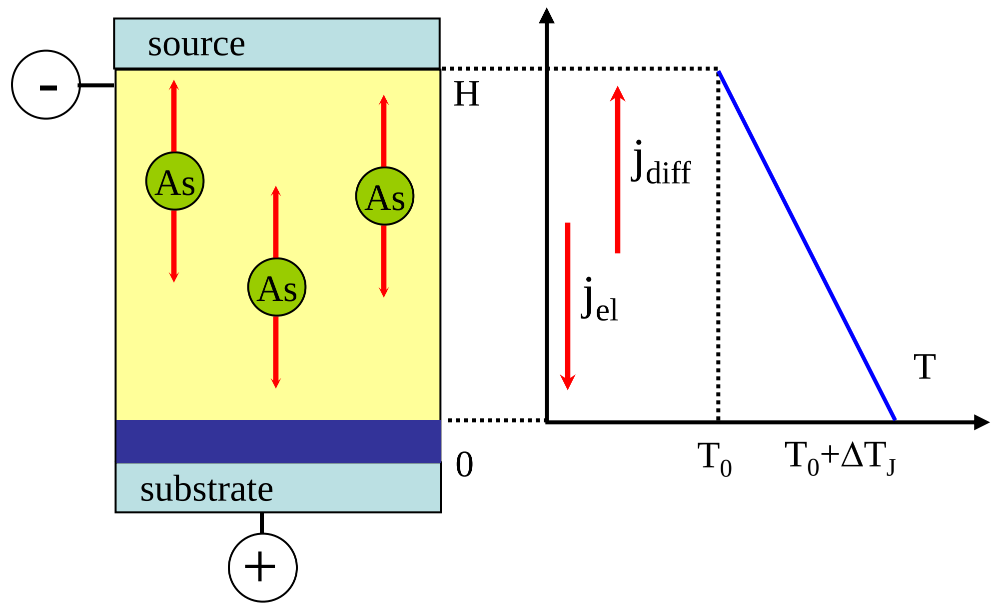
- LPEE system more complicated (stable electrical contacts needed)

- Joule effect limiting the crystal thickness

no Joule effect



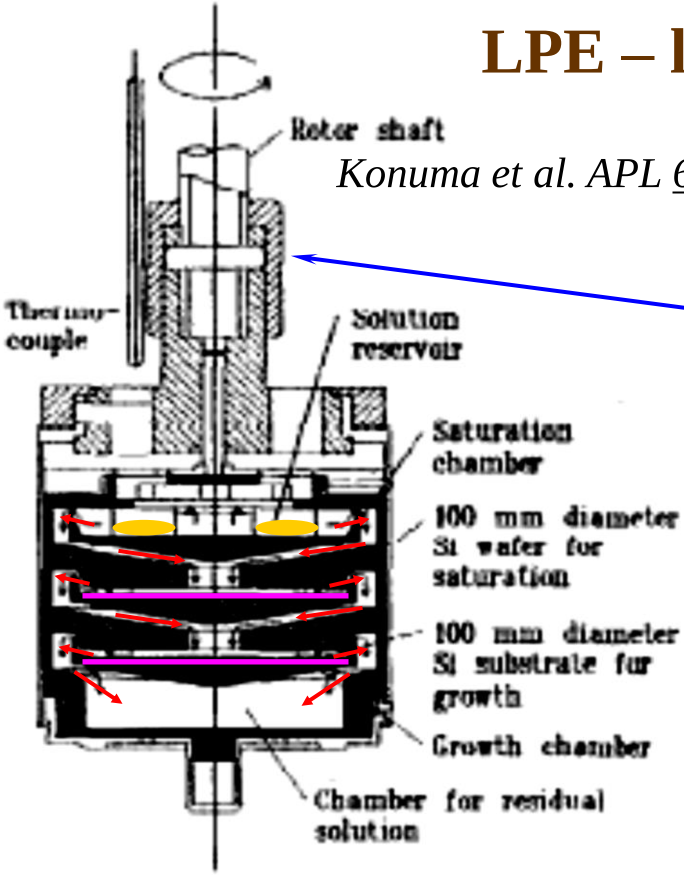
with Joule effect

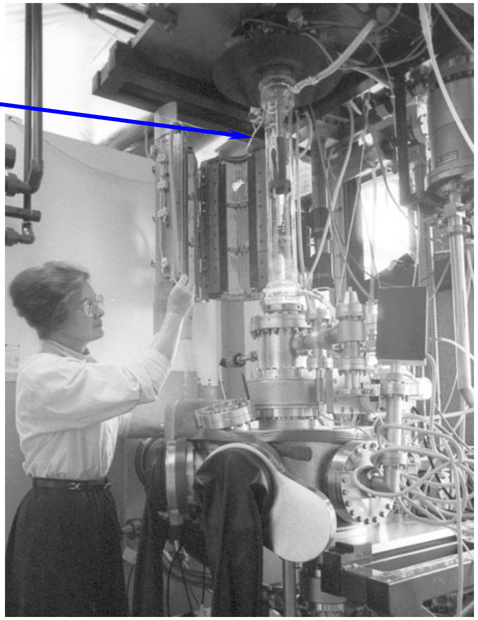


growth can be continued if $j_{el}\downarrow$

LPE – low dimensional structures

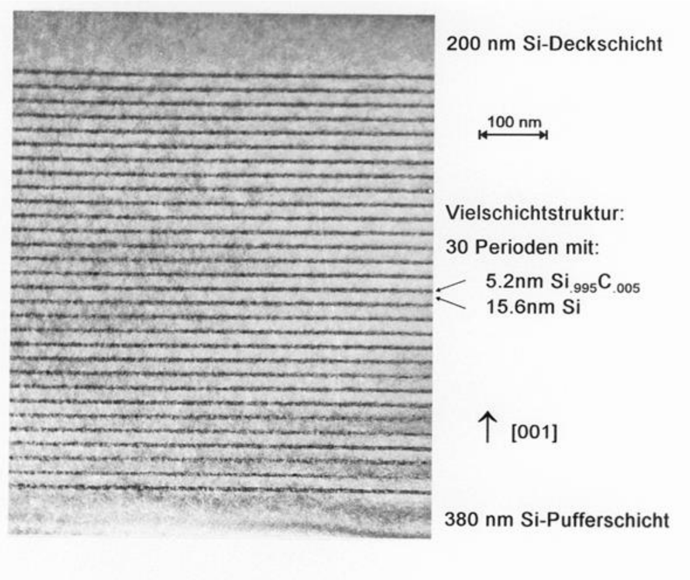
Konuma et al. APL 63 (1993) 205





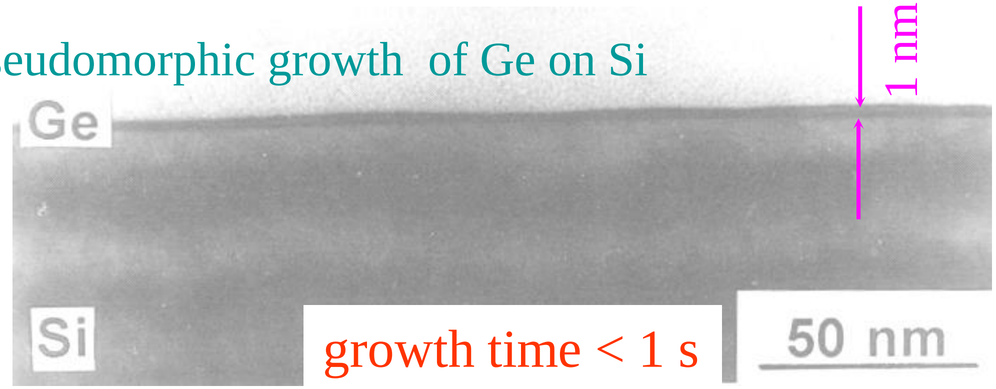
4” substrate !!!

Si 15.6 nm/$Si_{0.995}C_{0.005}$ 5.2 nm

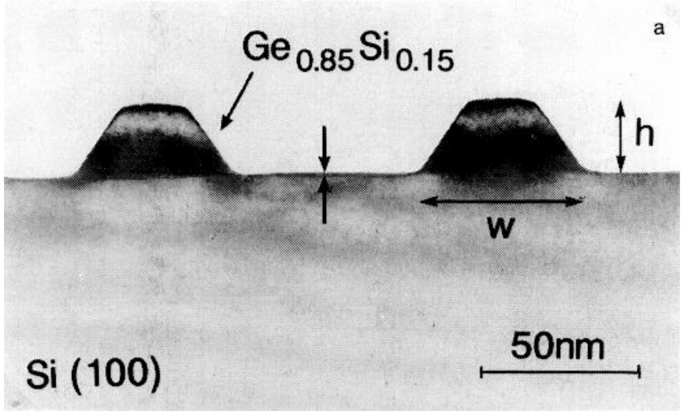


SiGe/Si QDs

pseudomorphic growth of Ge on Si



growth time < 1 s



LPE - summary

LPE

solution growth:
- low concentration of point defects
- high purity of the layers (segregation of impurities)
- selective area epitaxy easy
- wide range of compounds

epitaxy:
- ordered growth of multilayer crystalline structures

- technically simple (standard version)
- „cheap and easy”
- „safe” technique
- growth rate ~µm/min
- growth of low-dimensional structures very difficult

disadvantages:

limitations due to equilibrium nature of LPE growth
- doping limited by phase diagram (e.g. GaAs:Mn)
- structures requiring a high supersaturation (GaAs/Si) difficult to fabricate
- systems with limited solubility in solid (phase separation) difficult to grow

- no *in situ* growth monitoring possible (some possibilities in LPEE)

LPE considered as „old fashion” technology – wrong !!!
Every technology is important and valuable if properly used

for further reading on LPE

Handbook of Crystal Growth, Ed. D.T.J. Hurle
vol. 3, Elsevier 1994

- E. Bauser *Atomic mechanisms in semiconductor Liquid Phase Epitaxy*
- M.B. Small, E.A. Giess and R. Ghez *Liquid Phase Epitaxy*

E. Kuphal *Liquid Phase Epitaxy* Appl. Phys. A52 (1991) 380.

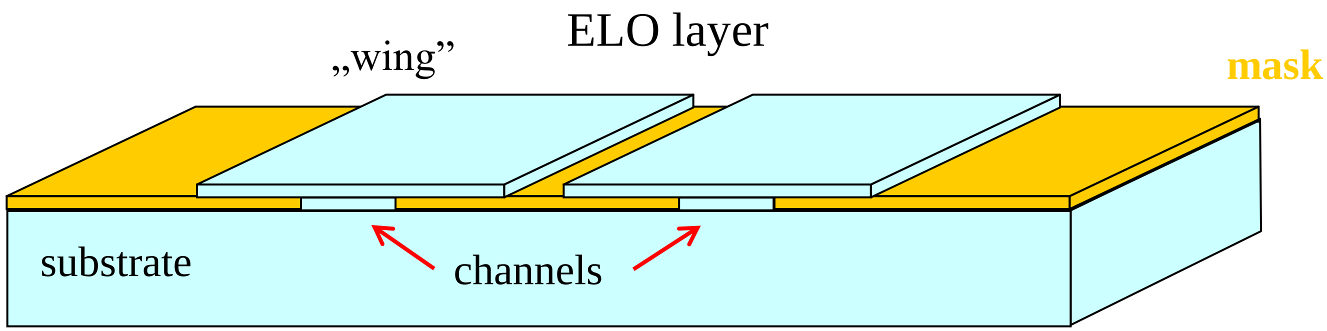
M.B. Small, I. Crossley *The physical processes occurring during liquid phase epitaxial growth* J. Cryst. Growth 27 (1974) 35.

M.G. Astles *Liquid Phase Epitaxial Growth of III-V Compound Semiconductor Materials and their Device Applications*, IOP Publishing 1990.

B. Pamplin (ed.) *Crystal growth*, Pergamon, 1974

K. Sangwal (ed.) *Elementary Crystal Growth*, SAAN Publishers, 1994.

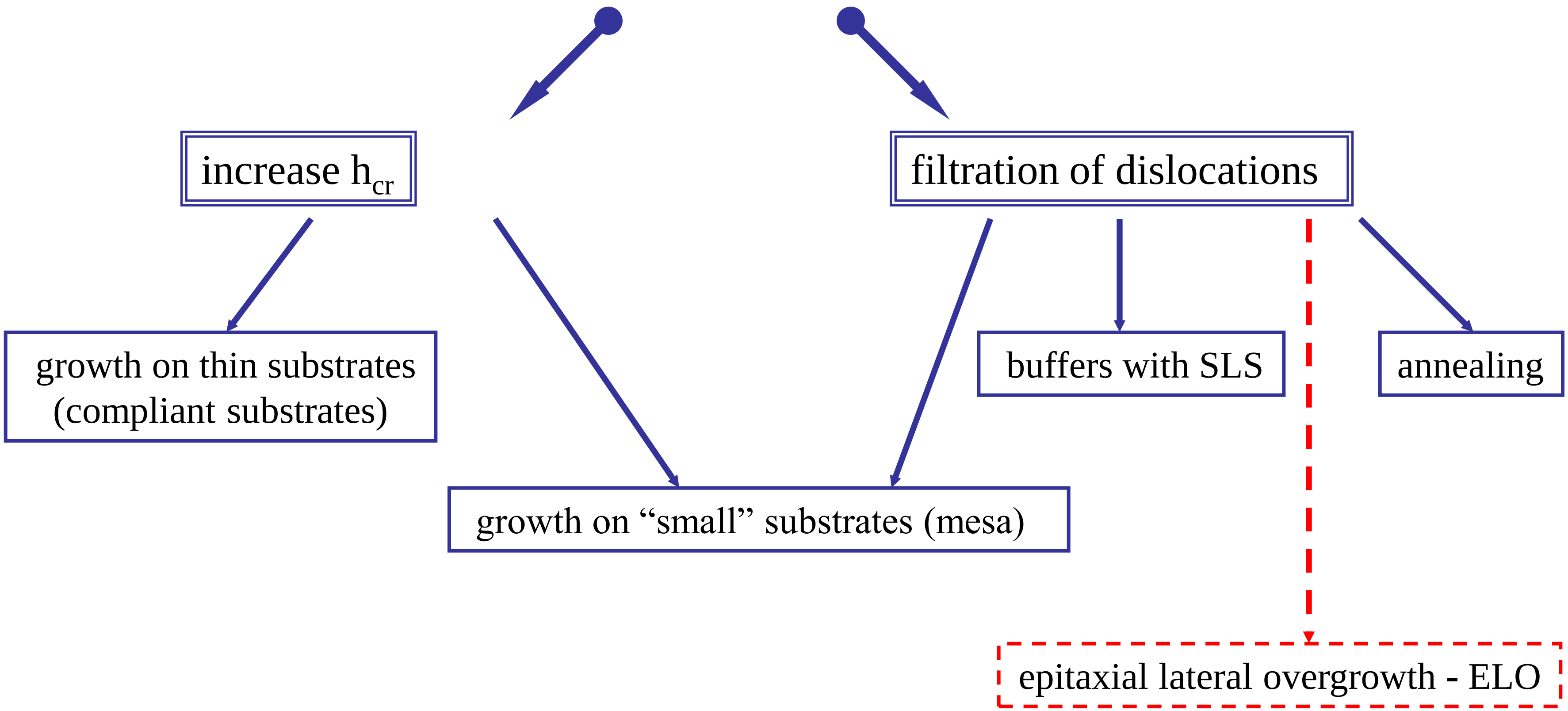
Epitaxial Lateral Overgrowth (ELO)



requirements:

- **high growth selectivity (no nucleation on the mask)**
- **fast lateral (horizontal) growth V_{lat}**
- **slow normal (vertical) growth V_{ver}**

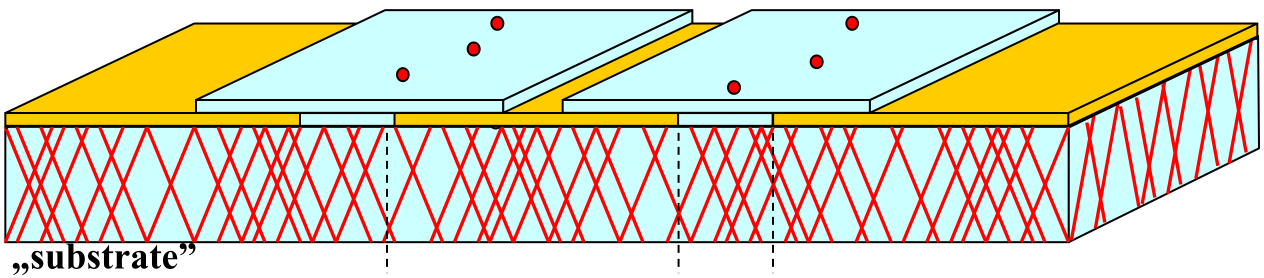
Methods to reduce defect density in lattice mismatched epitaxial structures - summary



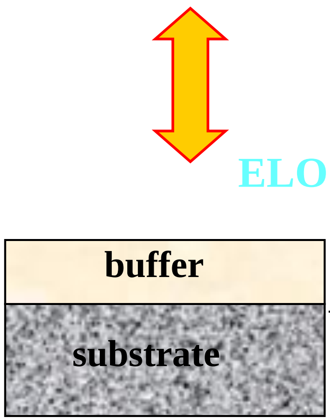
There are no universal method to reduce dislocation density in lattice mismatched heterostructures;
The best way is to avoid lattice mismatch – find the suitable substrate !!!

ELO = a method to reduce dislocation density in epitaxial structures

mask: SiO_2, Si_3N_4, W, ZrN, grafit, ...



MOVPE GaN: S = 5 – 20 μm; W = 2 - 5 μm
LPE GaAs: S = 100 – 500 μm; W = 6 - 10 μm



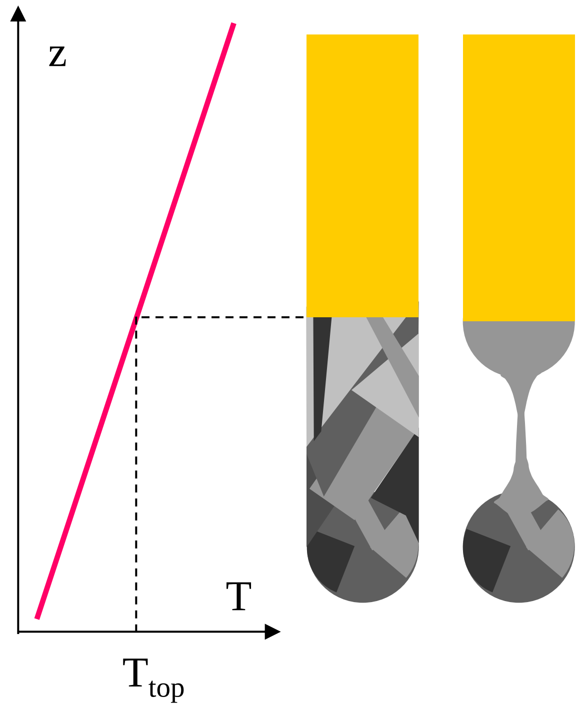
ELO	GaN	GaAs	$A_xB_{1-x}C$
buffer	GaN	GaAs	$A_xB_{1-x}C$
substrate	sapphire	Si	binary

new class of substrates with designed lattice parameter   a = f(x)

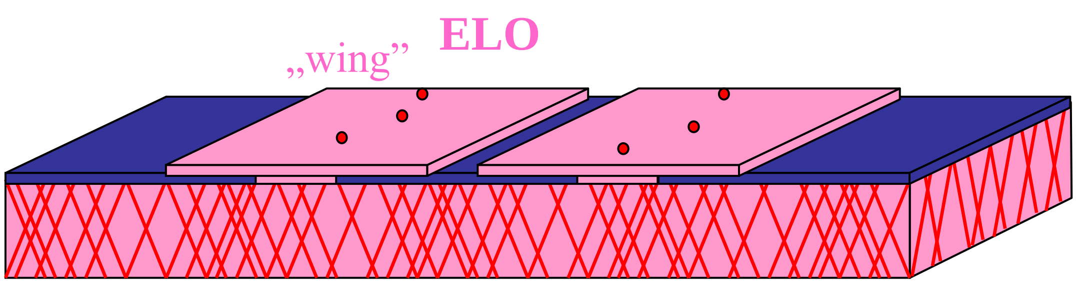
wide and thin ELO layers needed

dislocation filtration in ELO – is it a new idea?

Necking in Bridgman growth



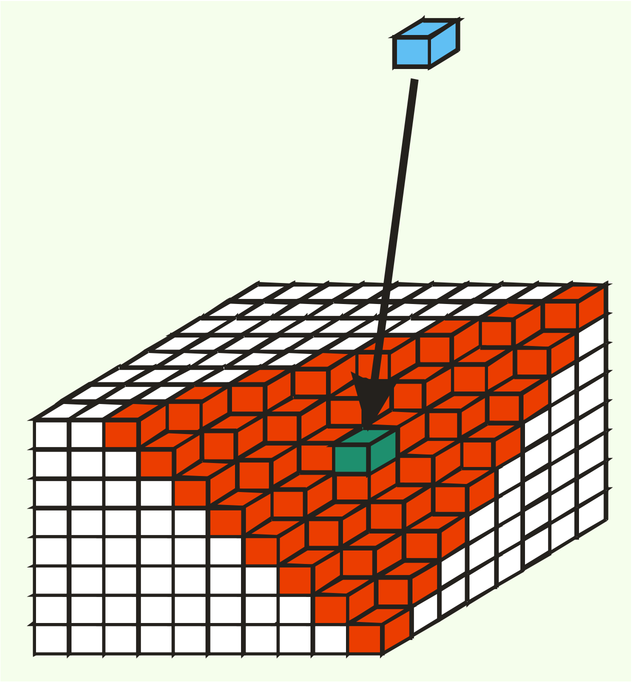
Cu crystal – Czochralski growth

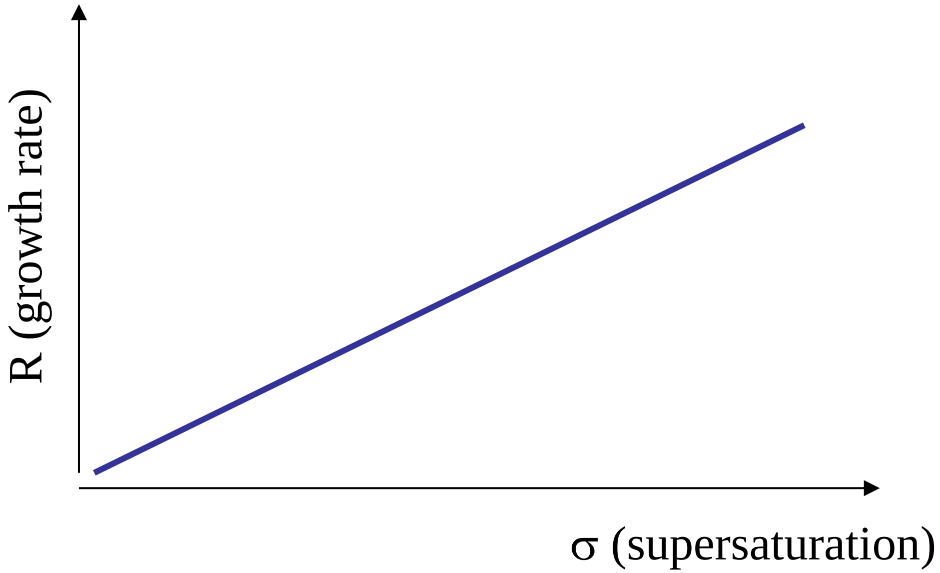


recipe: take from the seed info on crystal lattice; do not take defects;

Growth rate of various crystal faces (Krukowki's lecture)

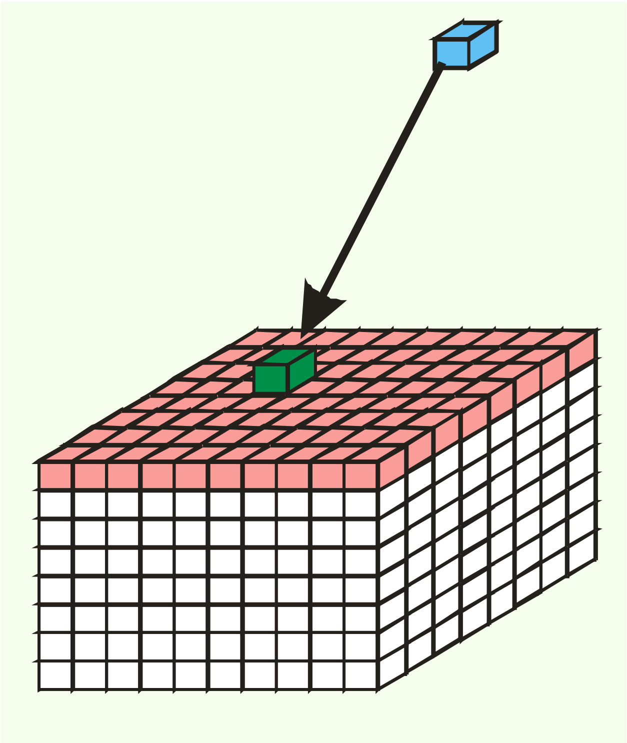
atomically rough surface

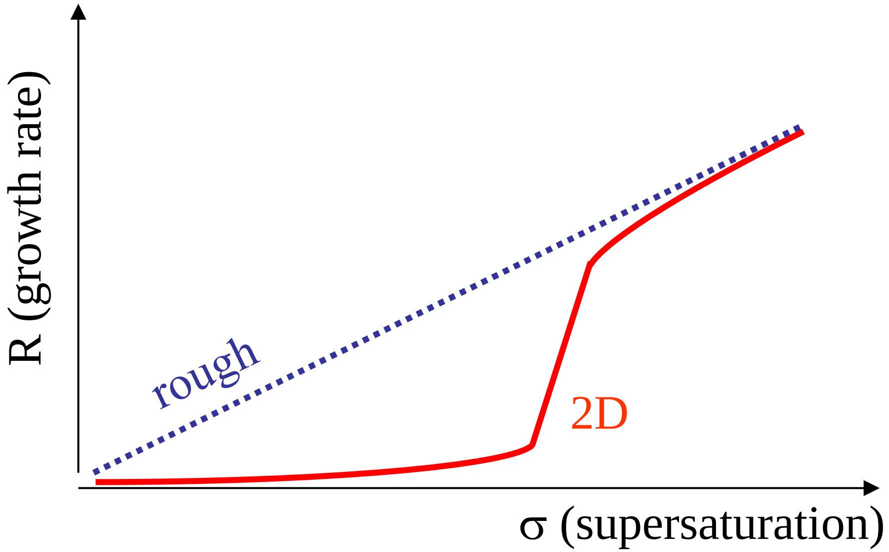




Growth rate of various crystal faces (Krukowki's lecture)

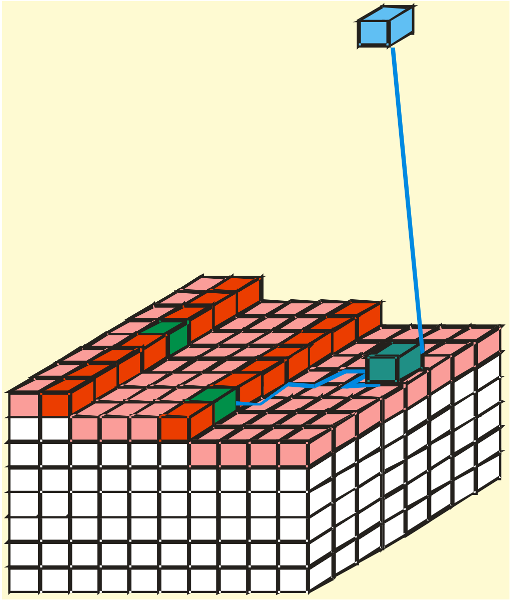
atomically smooth surface w/o dislocations (2D nucleation)

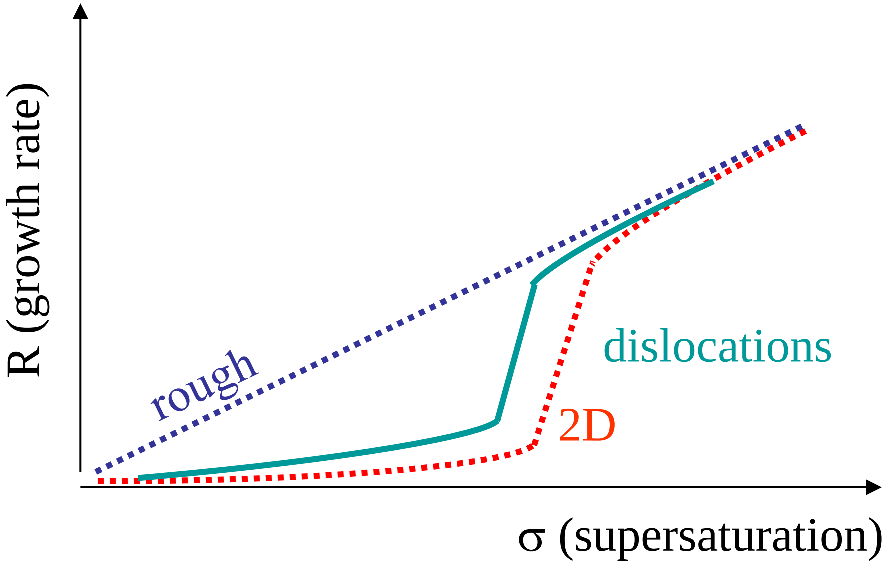




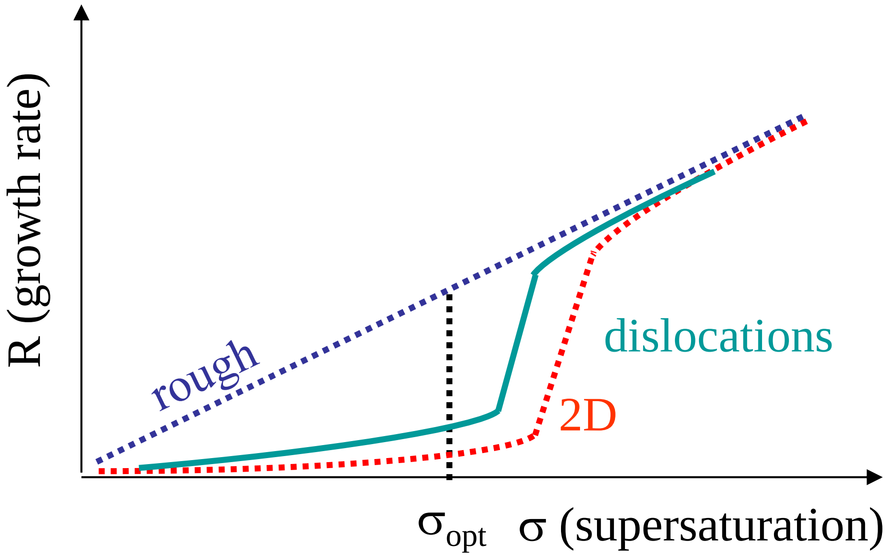
Growth rate of various crystal faces (Krukowki's lecture)

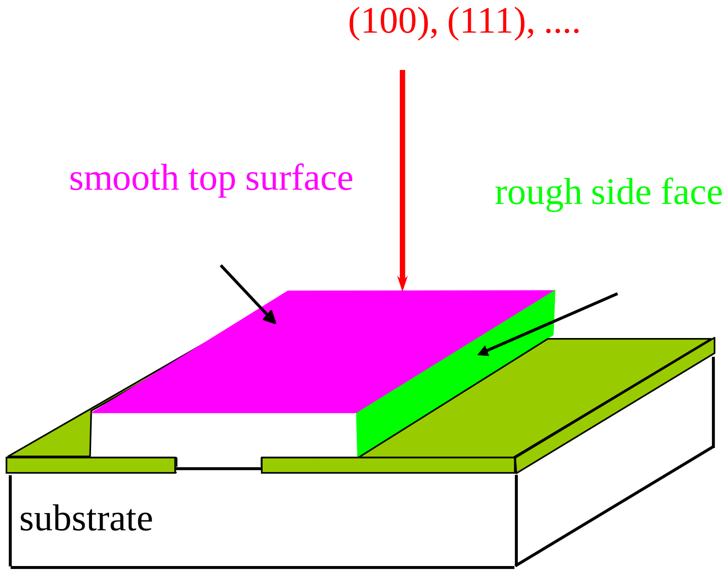
atomically smooth surface with dislocations





Mechanism of ELO growth





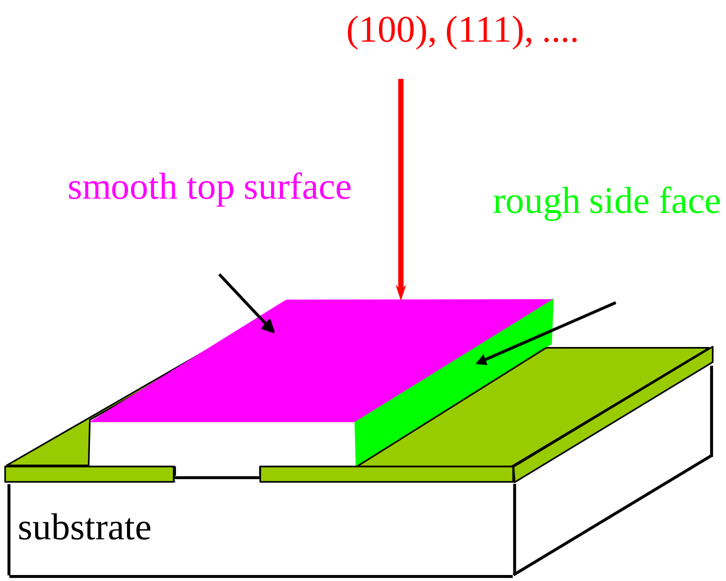
to get a high aspect ratio we need:

- **smooth top surface (low normal growth rate V_{ver})**
- **rough side face (high lateral growth rate V_{lat})**
- **adjust supersaturation to σ_{opt} - LPE perfect !!!**

- VPE, MOVPE, HVPE - possible

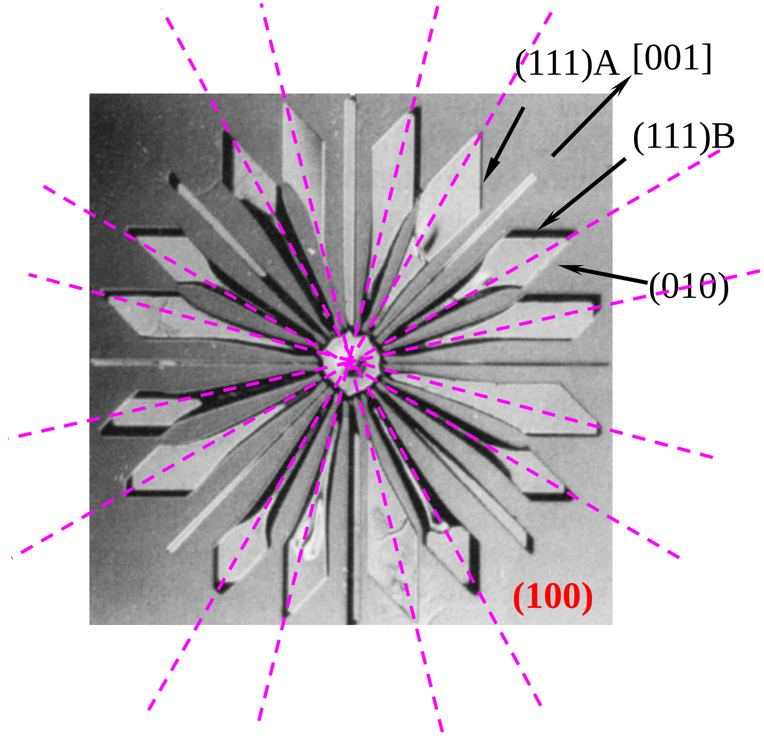
- MBE ???? problems

Mechanism of ELO growth



Zytkiewicz Cryst. Res. Technol. 1999

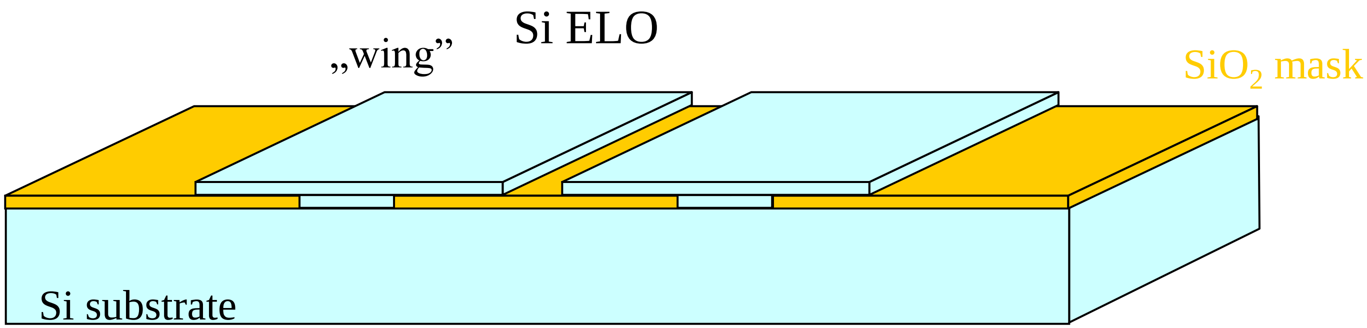
GaAs layer on (100) GaAs by LPE



8 equivalent window directions on substrate without miscut

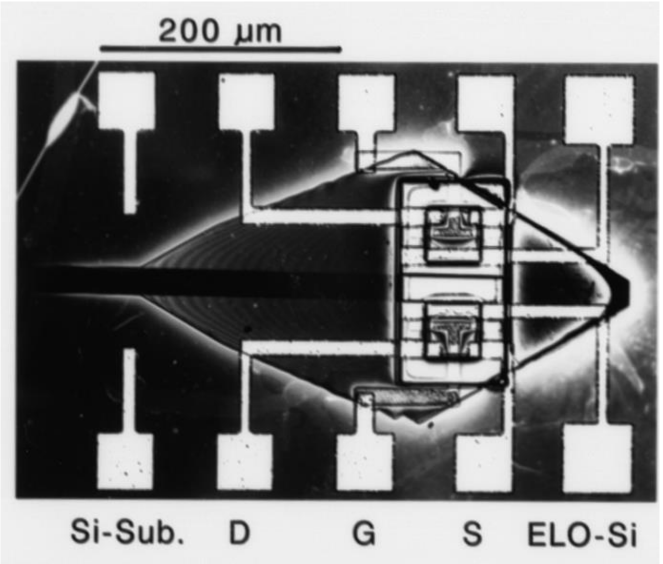
1 preferential window orientation on substrate with surface miscut

Application of ELO structures grown by LPE

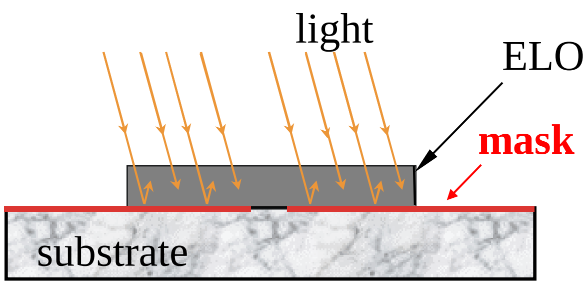


MOS transistor on ELO Si/SiO_2

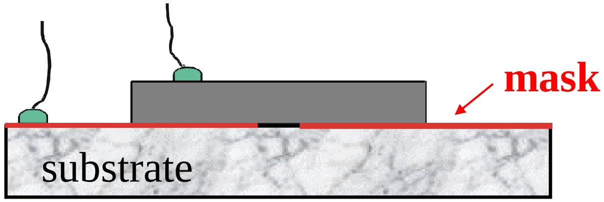
Bergmann et al. Appl. Phys. A (1992)



- silicon-on-insulator structures
- buried electrical contact/mirror

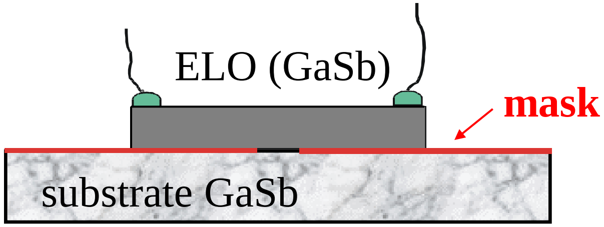


back mirror (photon recycling)



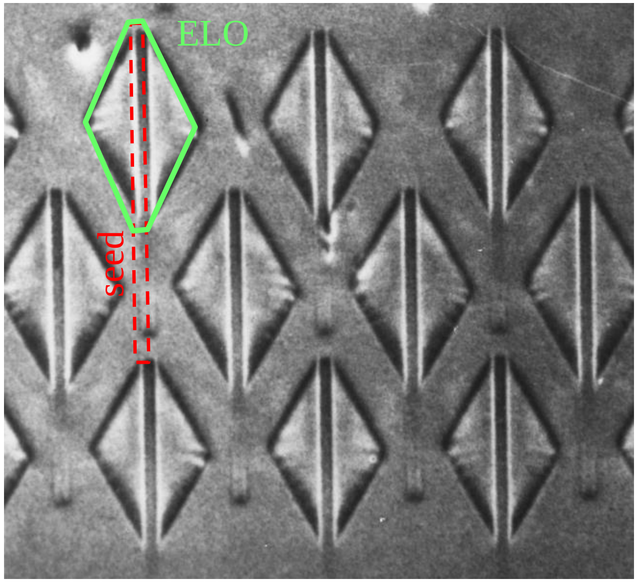
buried electrical contact

- electrical separation of epilayer from the substrate



ELO Si/SiO_2/Si by LPE

E. Bauser et al. Max-Planck Inst. Stuttgart



origin of strange ELO shape

- the case of dislocation-free Si substrate

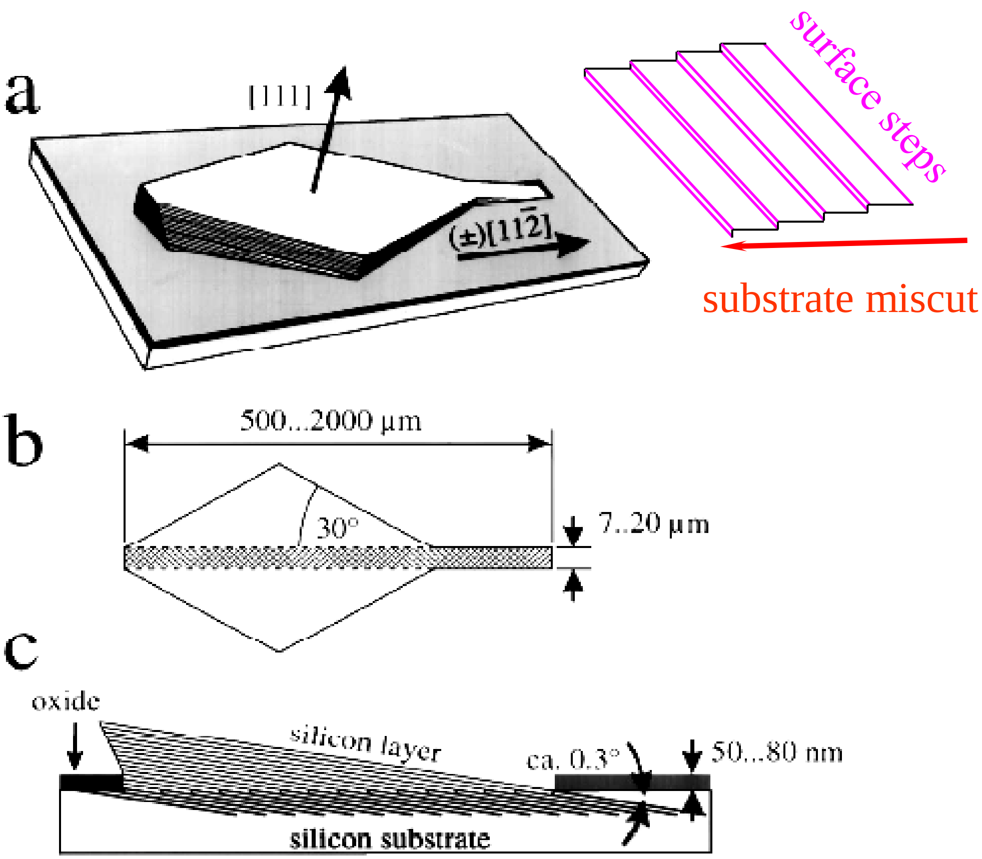


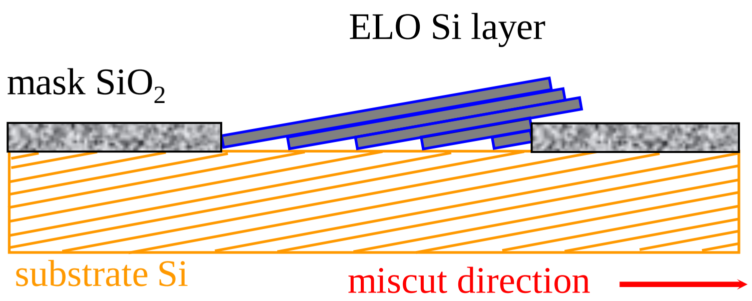
FIG. 1. Silicon layers grown from oxide-free seeding areas on {111} Si. Substrate partially masked by thermal oxide. Substrate off-orientation 0.3° in the [112] direction (schematic view). The crosshatched area in (b) indicates the seed window.

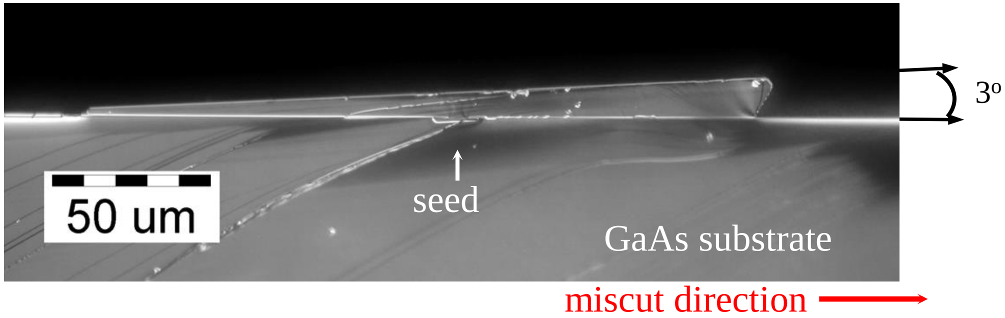
Mechanism of ELO growth on dislocated substrates

comparison

ELO on dislocation-free substrate Si/Si	ELO on dislocated substrate GaAs/GaAs

Zytkiewicz et al. Cryst. Res. Technol. 2005





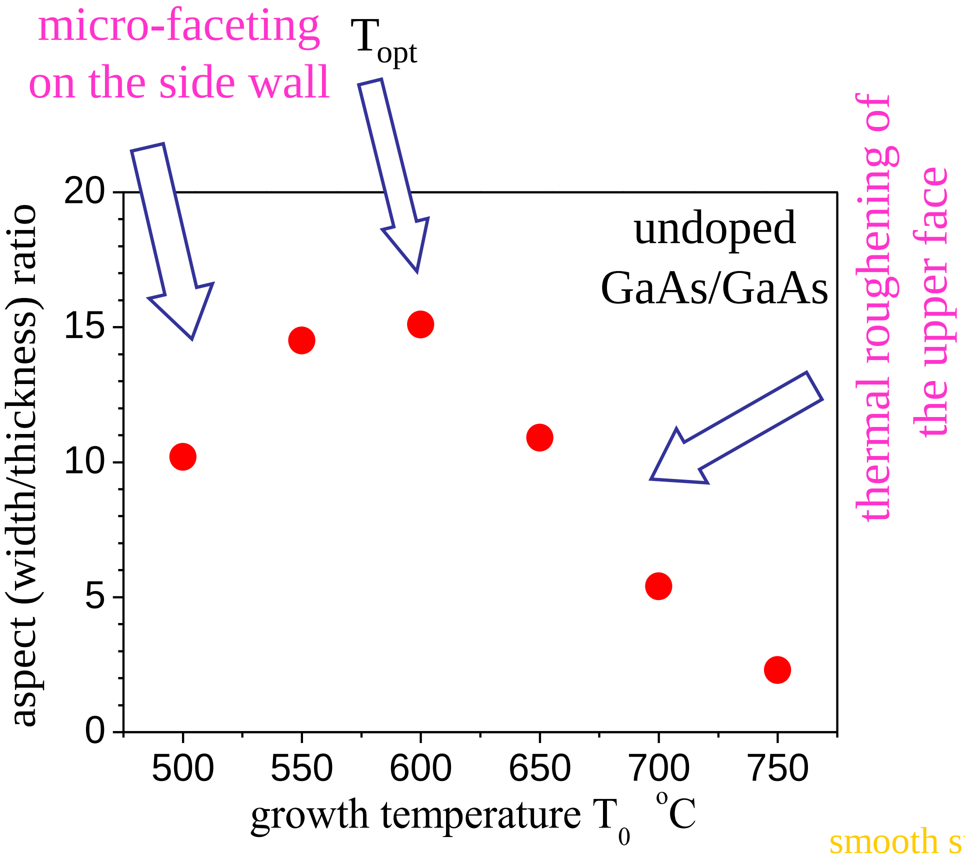
growth in the miscut direction only
(for low supersaturation)

growth in all directions

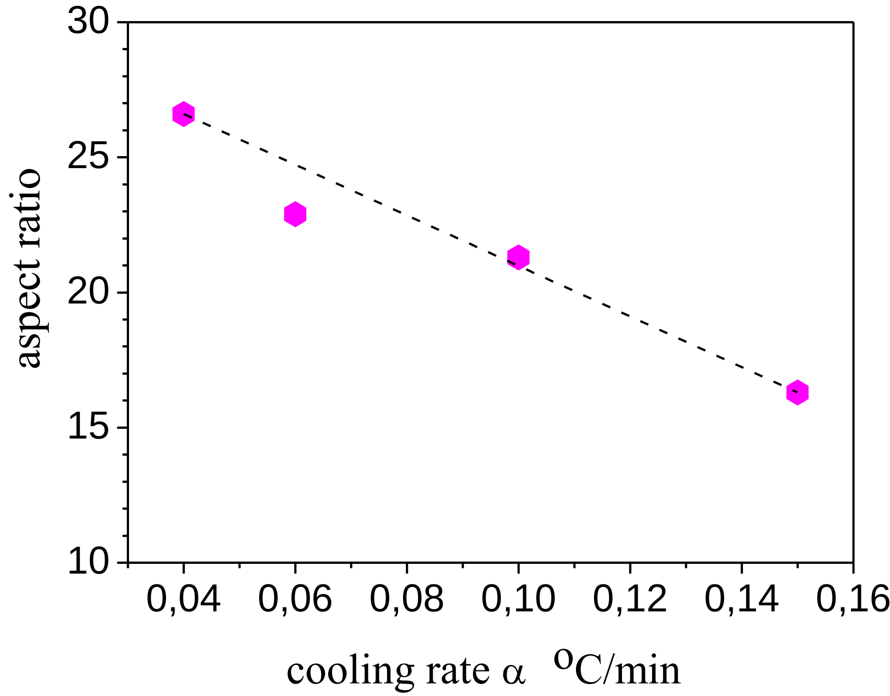
on dislocated substrate ELO growth possible w/o substrate miscut
(miscut used sometimes though; e.g GaAs/Si)

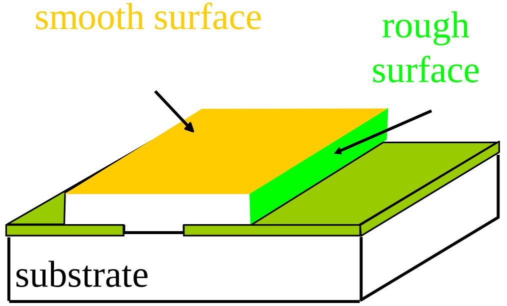
ELO – optimization of supersaturation in LPE

growth temperature



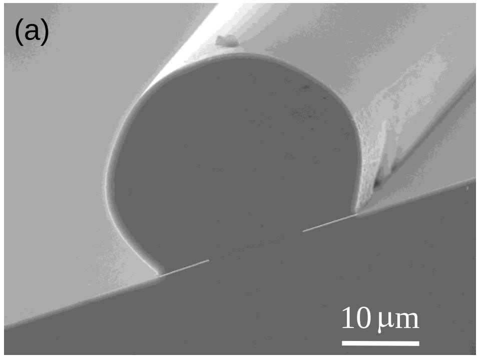
ELO GaAs - cooling rate



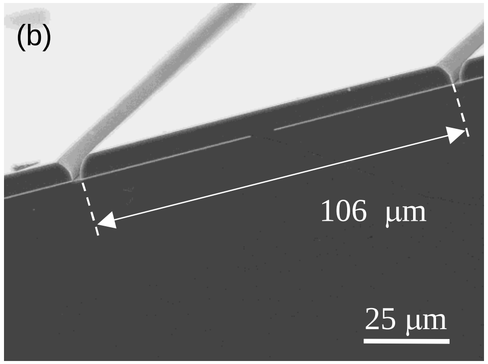


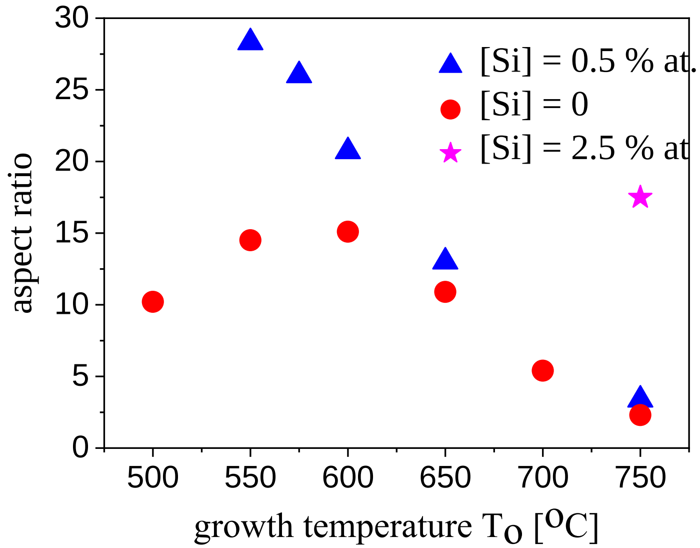
ELO – influence of doping on the aspect ratio (LPE)

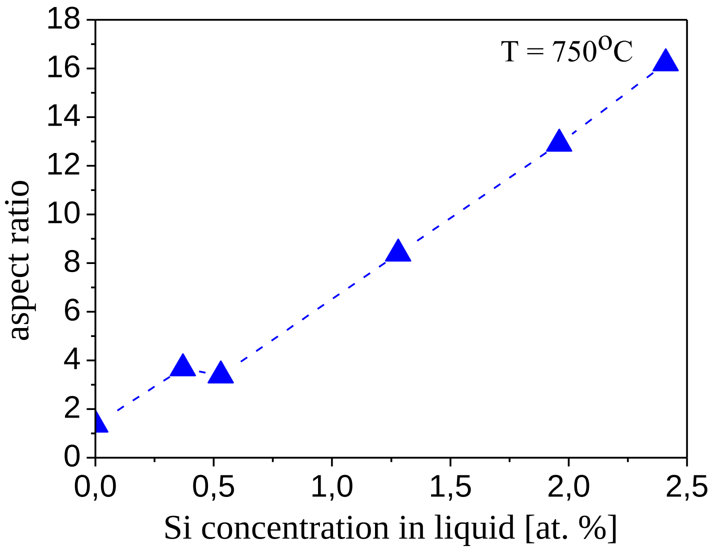
ELO GaAs - undoped

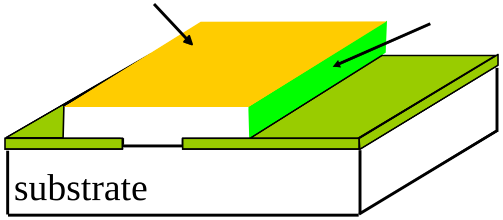


ELO GaAs - Si doped

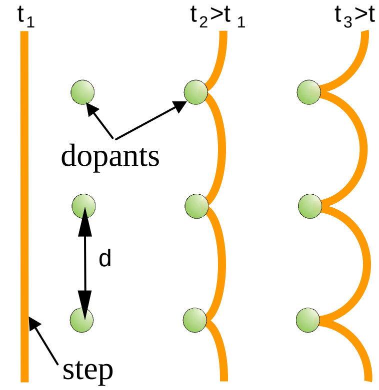








Model



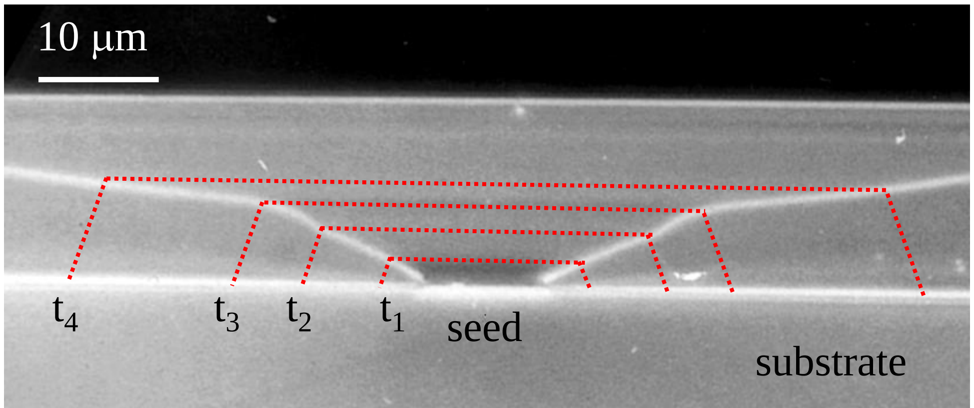
steps must squeeze between immobile impurities; flow of steps on upper surface slower

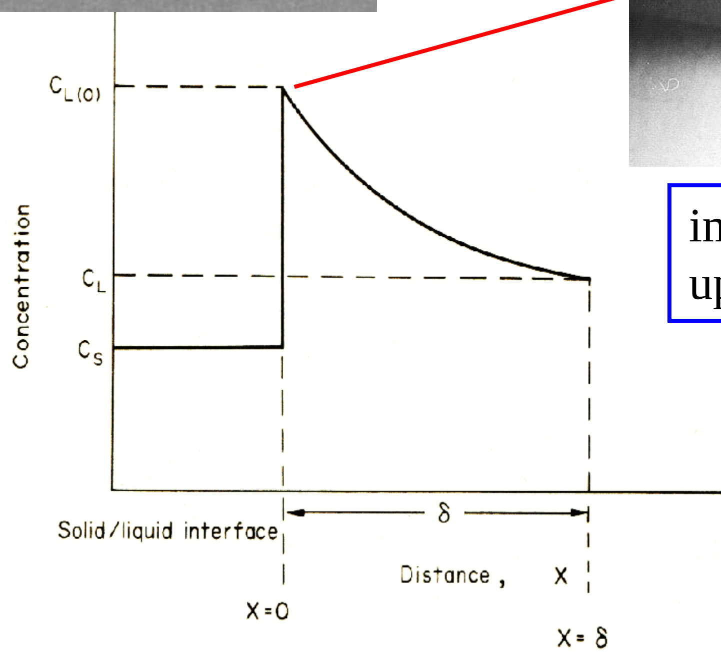
V_{ver} decreases V_{lat} increases

ELO by LPE – dopant incorporation

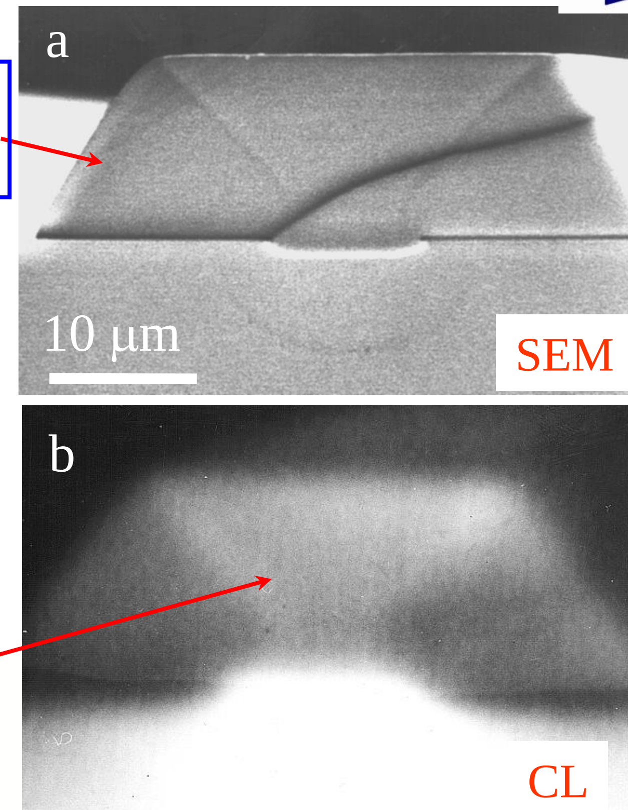
doping vs. growth rate ⇔ lecture by T. Słupiński

how ELO develops …





ELO GaAs:Te

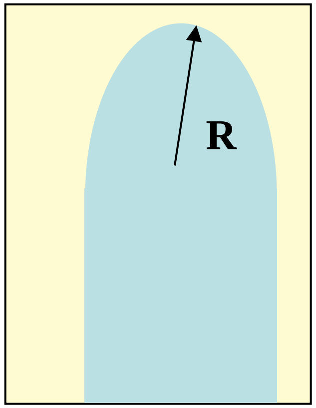


rough face – no segregation k_0

impurity segregation at upper face k_{eff}

Gibbs-Thomson effect $\Rightarrow$ S. Krukowski's lecture

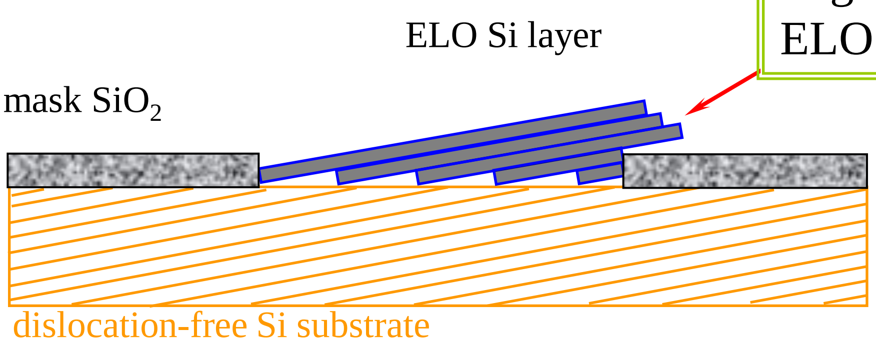
Gibbs – Thomson effect a – phase equilibrium on curved surface depends on radius of phase boundary



Γ - capillarity constant (~ 10^{-7} cm = 1 nm)

$$p(R) = p(\infty)\cdot\left(1+\frac{\Gamma}{R}\right) \qquad C(R) = C(\infty)\cdot\left(1+\frac{\Gamma}{R}\right)$$

equilibrium pressure (solute concentration) on curved surface is larger than on the planar one



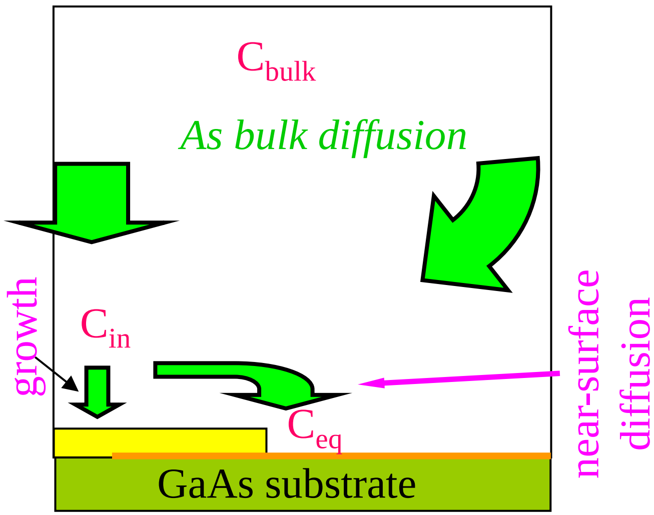
large curvature (small R) at the beginning of LPE ELO growth

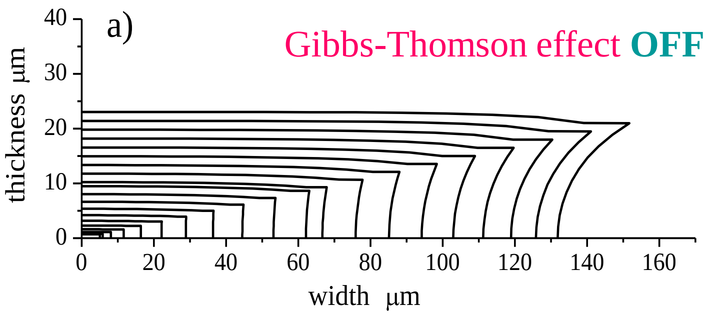
Silier et al. J. Cryst. Growth 1996

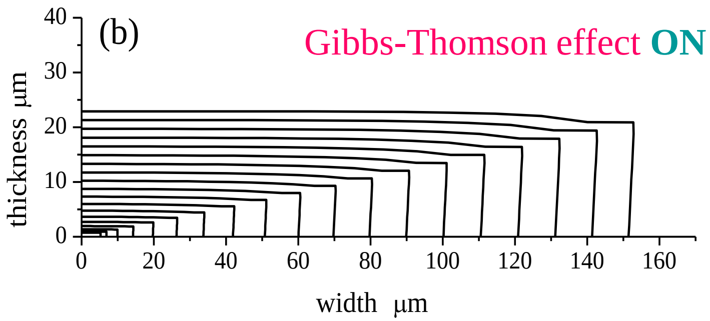
initial liquid supercooling ~1.8°C needed to allow the ELO layer to get out of the channel over the mask

Gibbs-Thomson effect ⇒ S. Krukowski's lecture

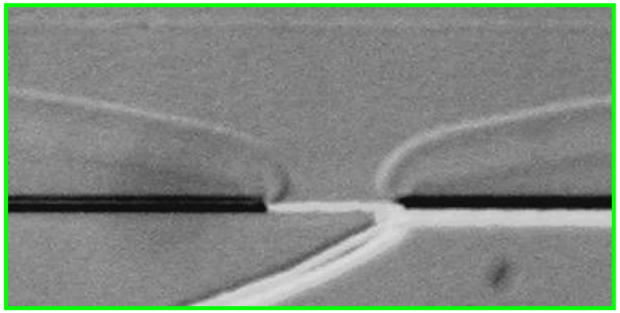
simulations: ELO of GaAs byLPE

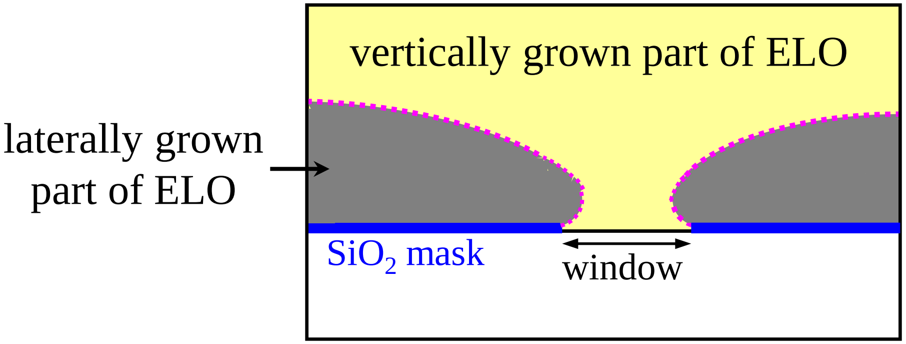






Gibbs-Thomson effect:
ELO of GaAs by LPE

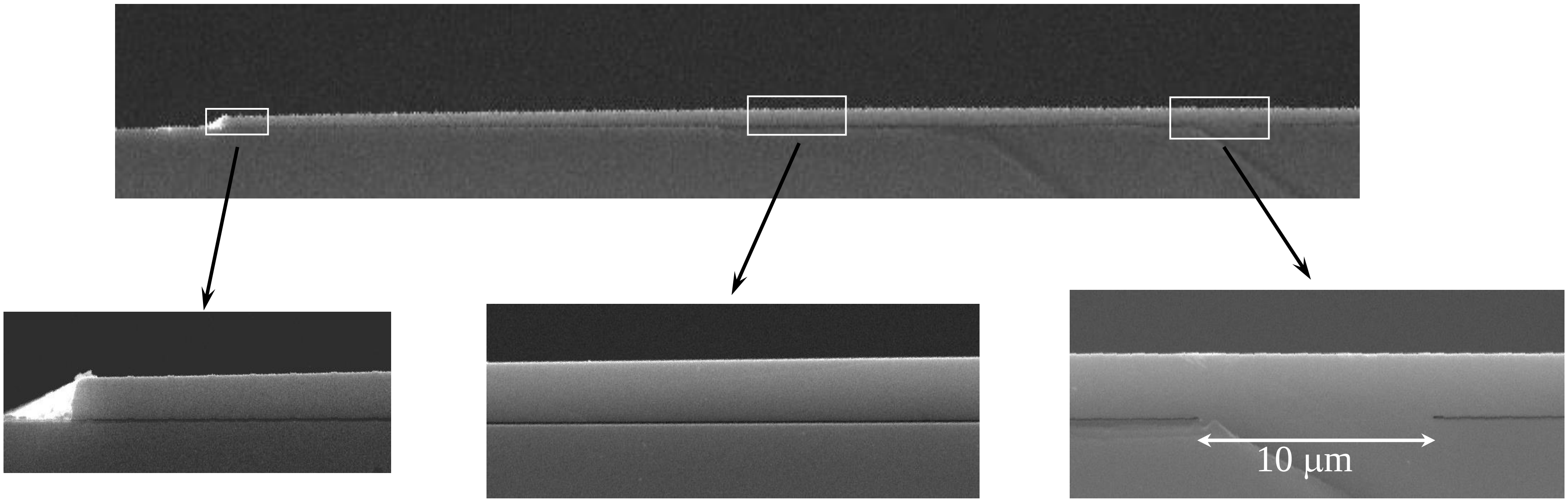




substrate dislocations make ELO growth possible without initial supersaturation of the solution

GaAs ELO layers on GaAs substrates by LPE

L = 172 µm; t = 2.8 µm



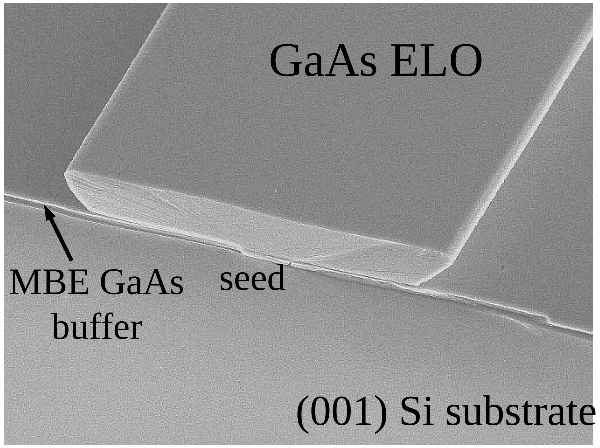
thickness t = 2.8 µm
width of the wing L = 172 µm

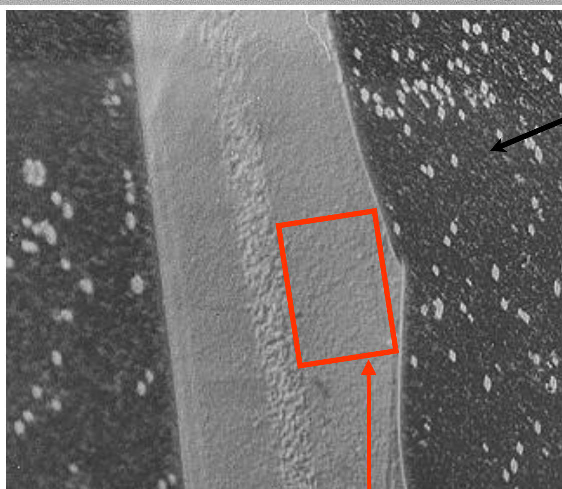
→ aspect ratio 2L/t = 126

Why the layer is thinner at the edge?
nonuniform growth …
bowing …

Filtration of dislocations in ELO - examples

LPE - GaAs/Si

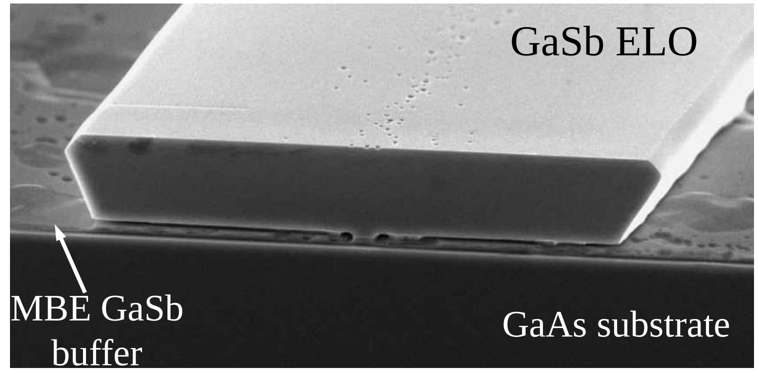


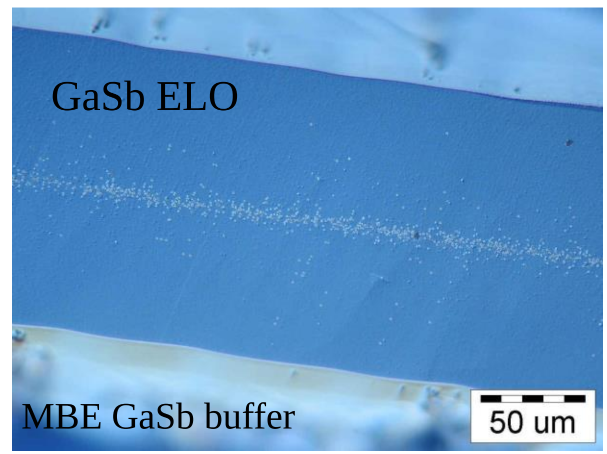


EPD > 10^{-8} cm^{-2}

device

LPE - GaSb/GaAs

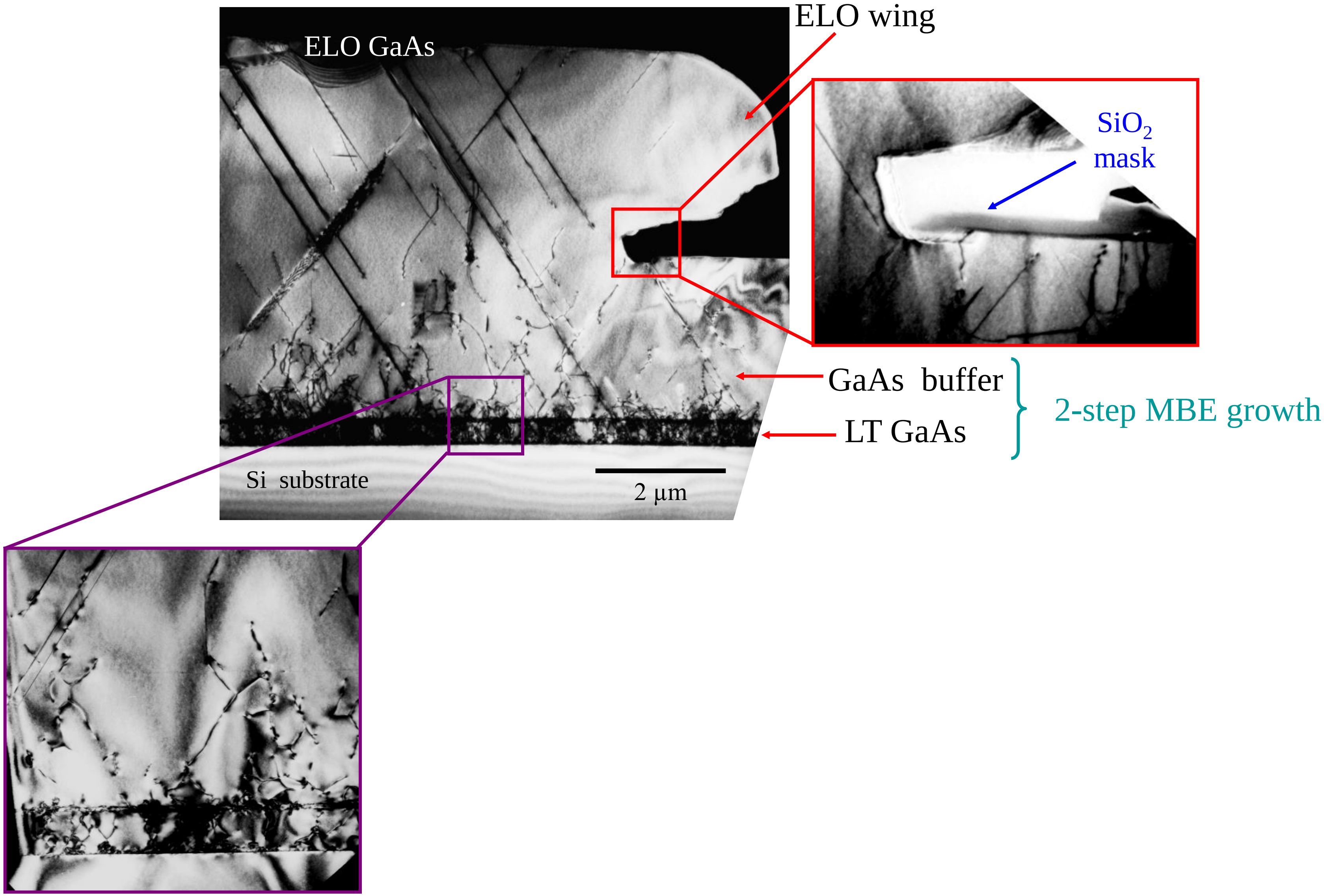




after etching

MBE grown GaAs/Si (GaSb/GaAs) templates; ELO by LPE

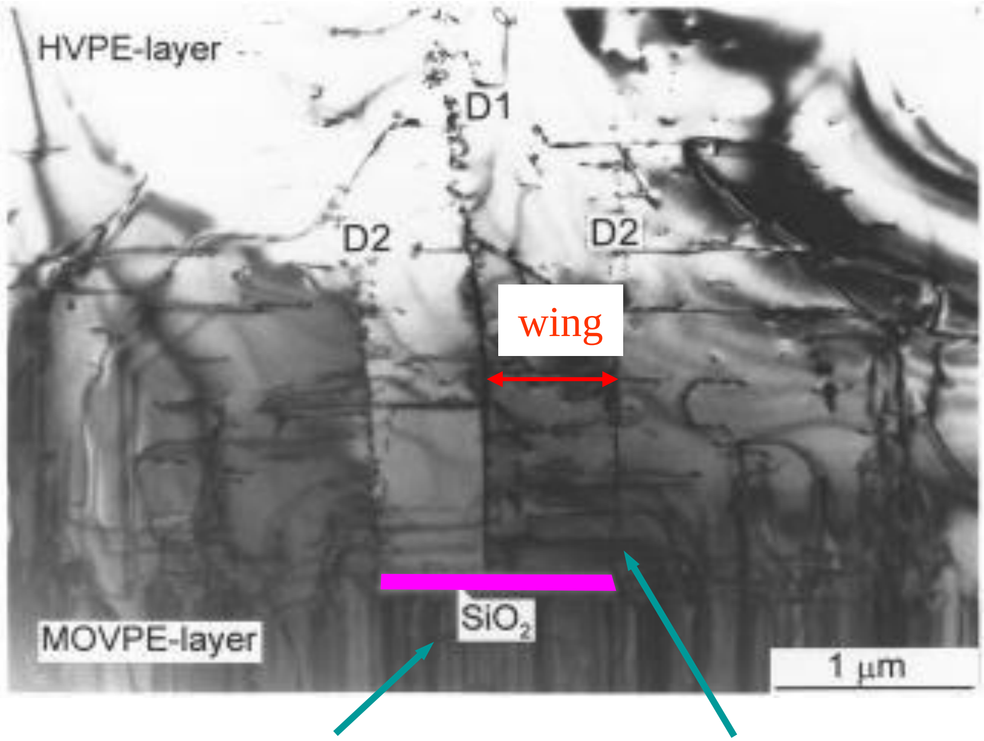
Filtration of dislocations in ELO: TEM of GaAs/Si



Filtration of dislocations in ELO: TEM of HVPE GaN/sapphire

Sakai et al. APL 1998

TEM



dislocations blocked
by the mask

bending of TD's
in the window area !!!

width of the ELO wing

	MOVPE GaN*	LPE GaAs/Si**	LPE GaAs/GaAs
wing width L	≤ 5 µm	≤ 90 µm	≤ 200 µm

* Fini et al. JCG (2000) ** Chang et al. JCG (1998)

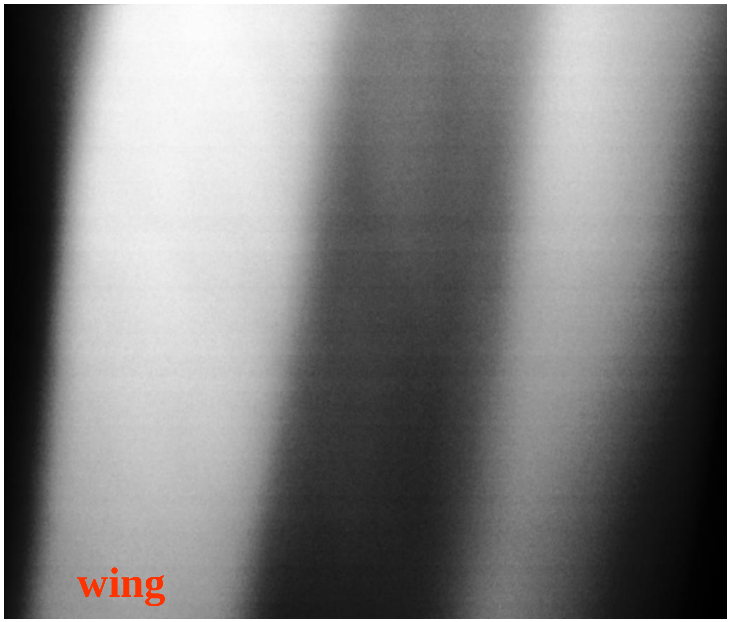
Filtration of dislocations in ELO: cathodoluminescence

Zytkiewicz Thin Solid Films 412 (2002) 64

Yu et al. MRS Internet Nitride Semicond. Res. 1998

LPE GaAs/Si

integrated CL

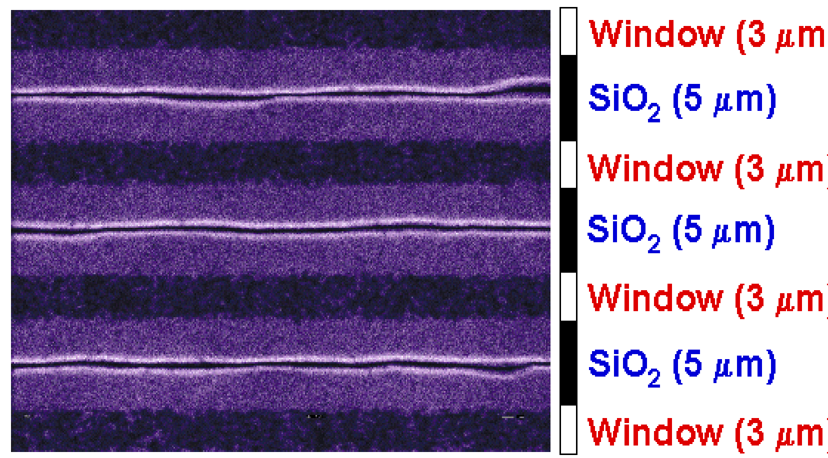


GaAs grown over the seed

MOVPE GaN on sapphire

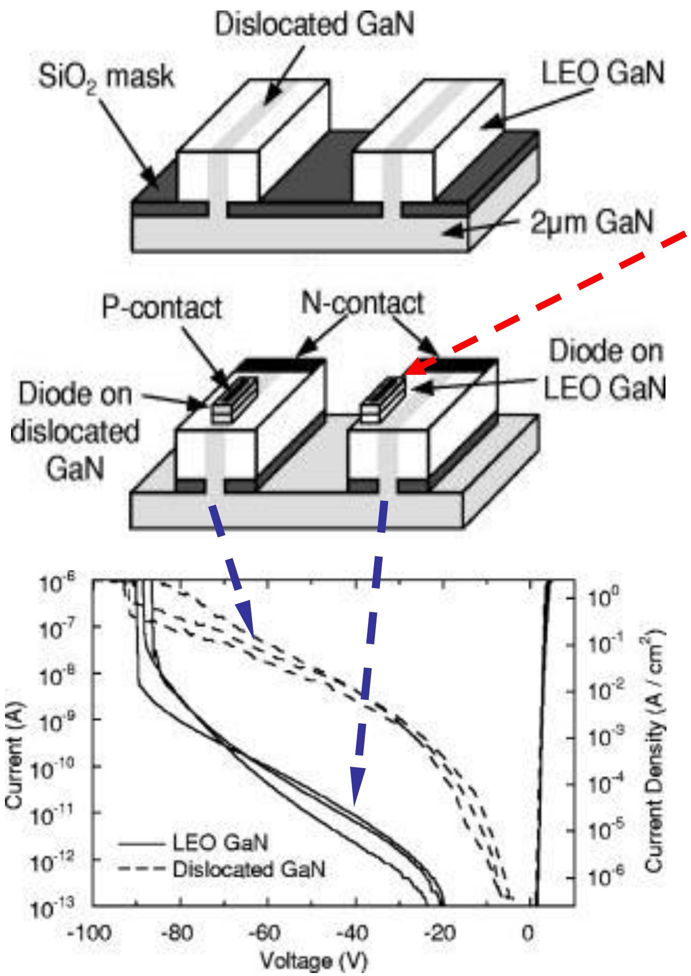
band edge emission 365 nm

wing
wing



ELO structures for devices

Kozodoy et al. APL 1998

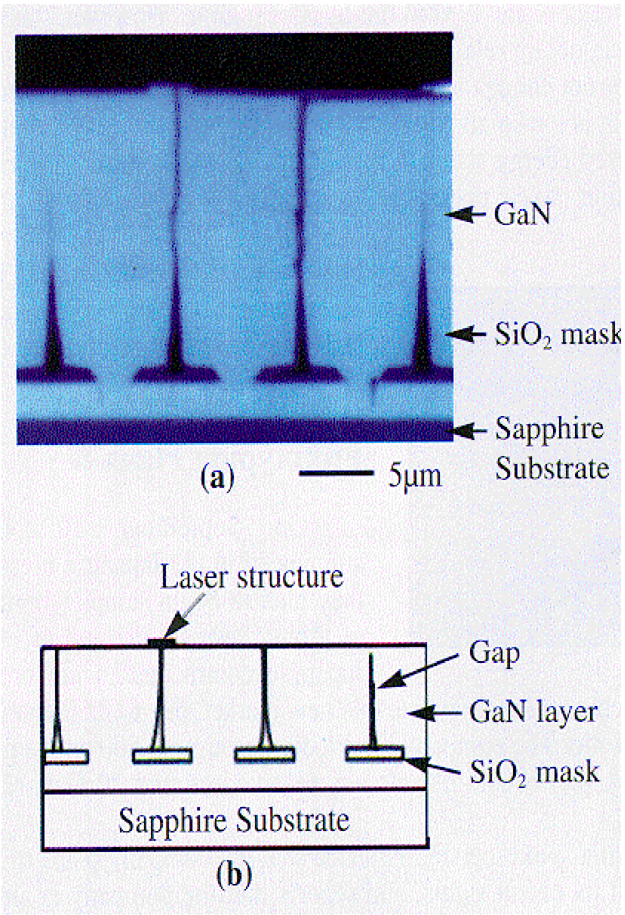


!!!

large leakage current due to TD

Semicond. Res. 4S1, G1.1 (1999)

CW RT blue LD - Nichia



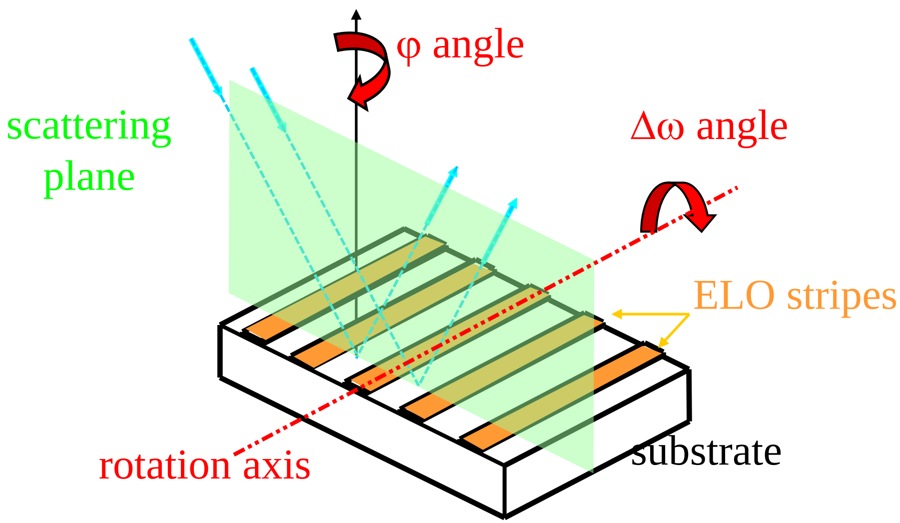
on the wing j_{th} = 3 kA/cm^2

on the window j_{th} = 6-9 kA/cm^2

Strain in ELO layers

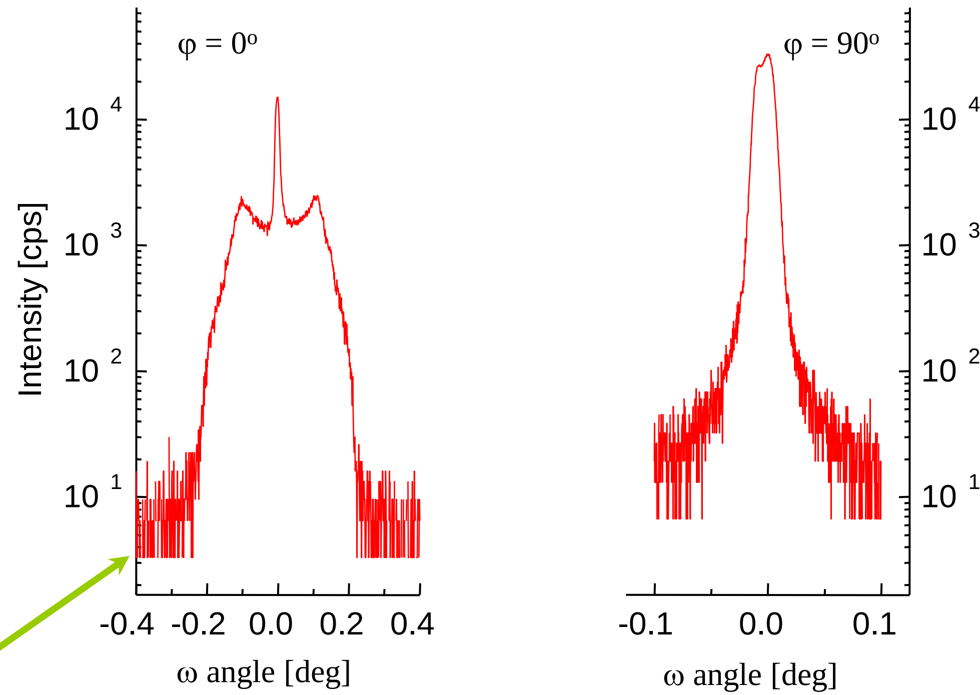
XRD – lecture by M. Leszczyński

XRD geometry



ELO GaAs on SiO_2-coated GaAs

Zytkiewicz et al. JAP 1998

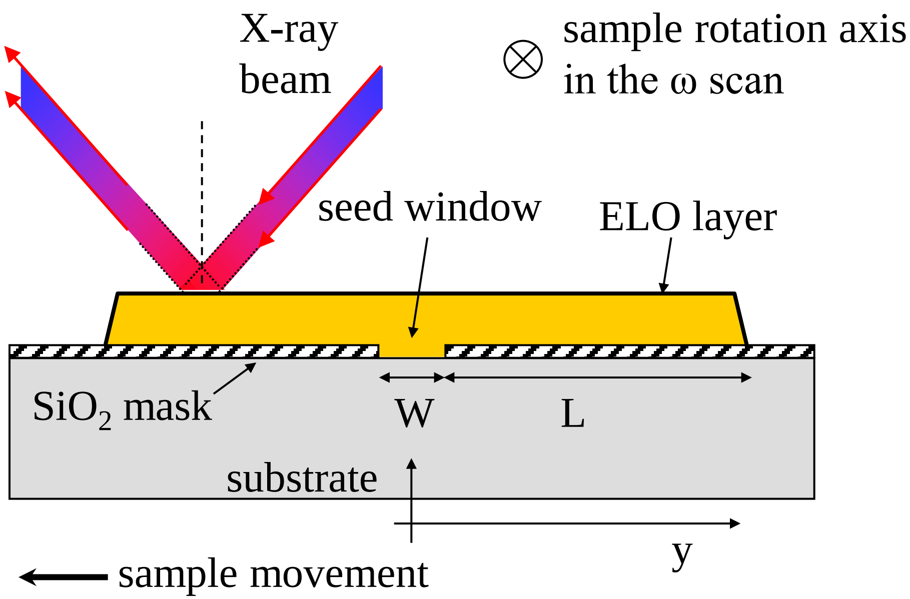


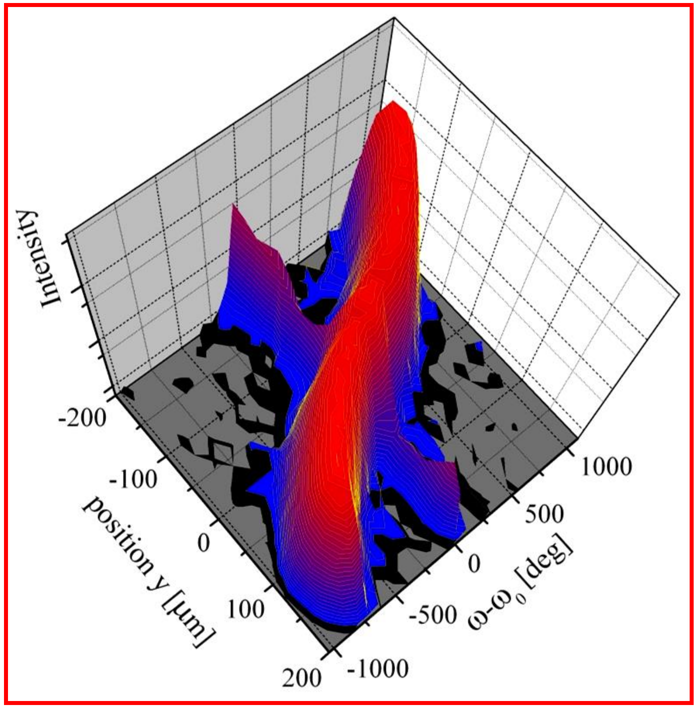
broadening of the RC:

- different values of lattice parameters ?
- different orientations of the ELO stripes ?
- <u>bowing </u>– direction ?

"typical" GaAs epilayer

Strain in ELO layers – local XRD

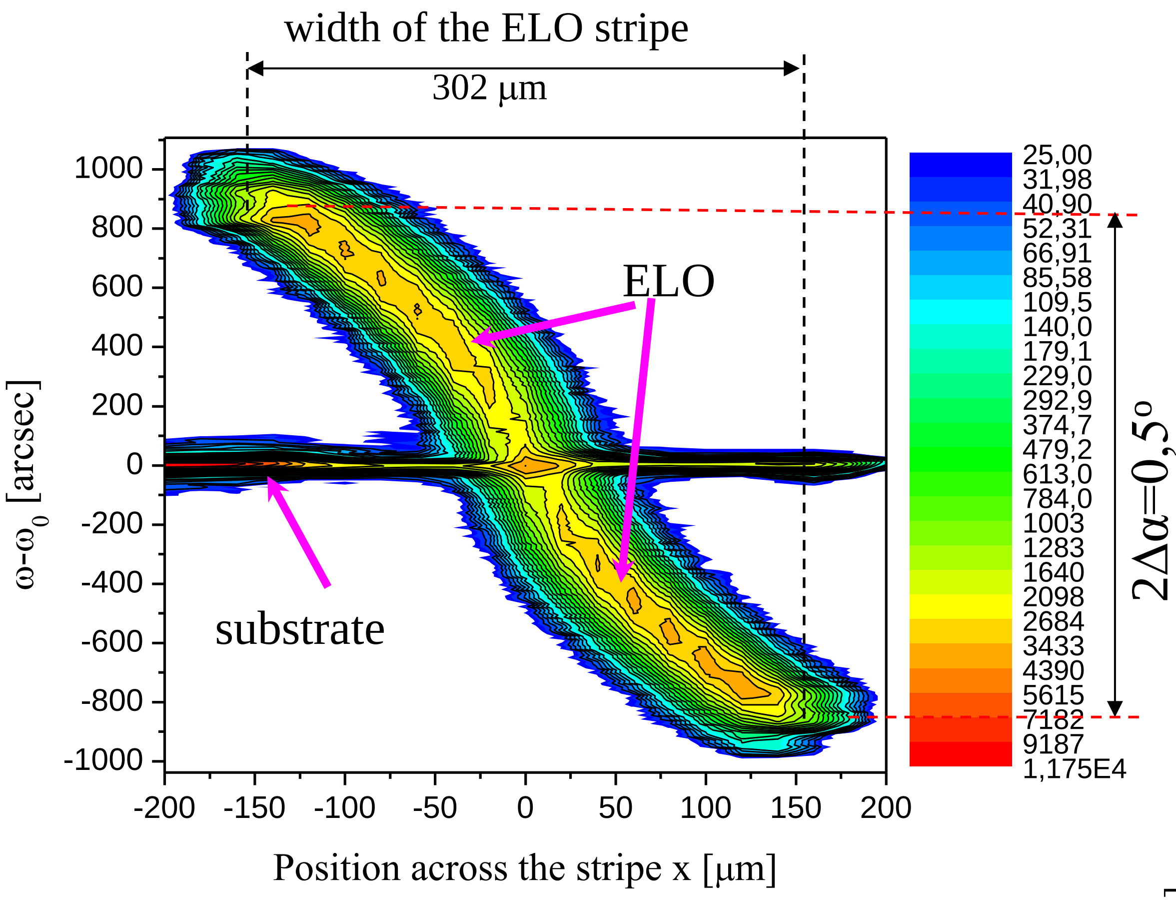


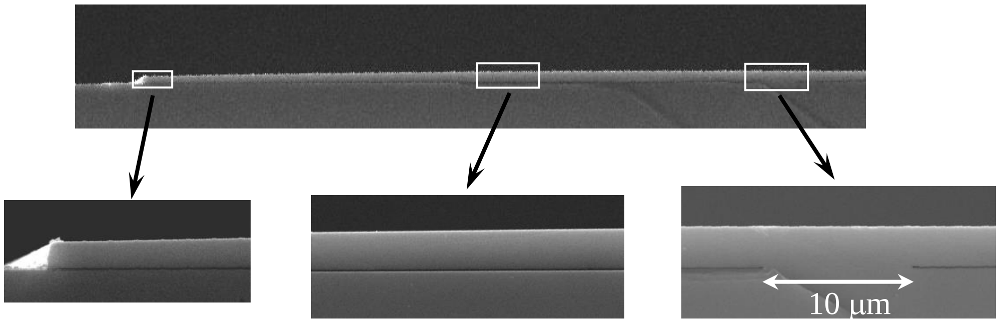


X-ray beam 5 – 10 μm × 0.5 – 10 mm
sample movement step 5 – 20 μm
RC, RSM, … measured *locally* → Rocking Curve mapping

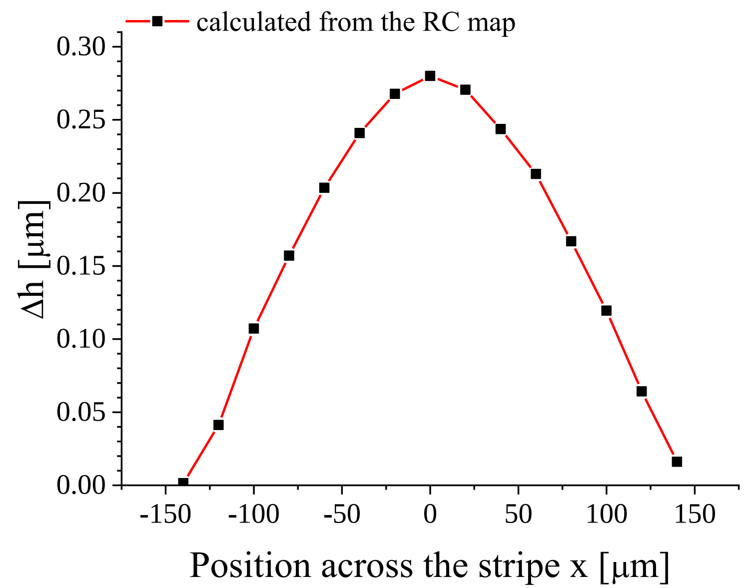
Strain in ELO layers – local XRD

Czyzak et al. Appl. Phys. A 2008



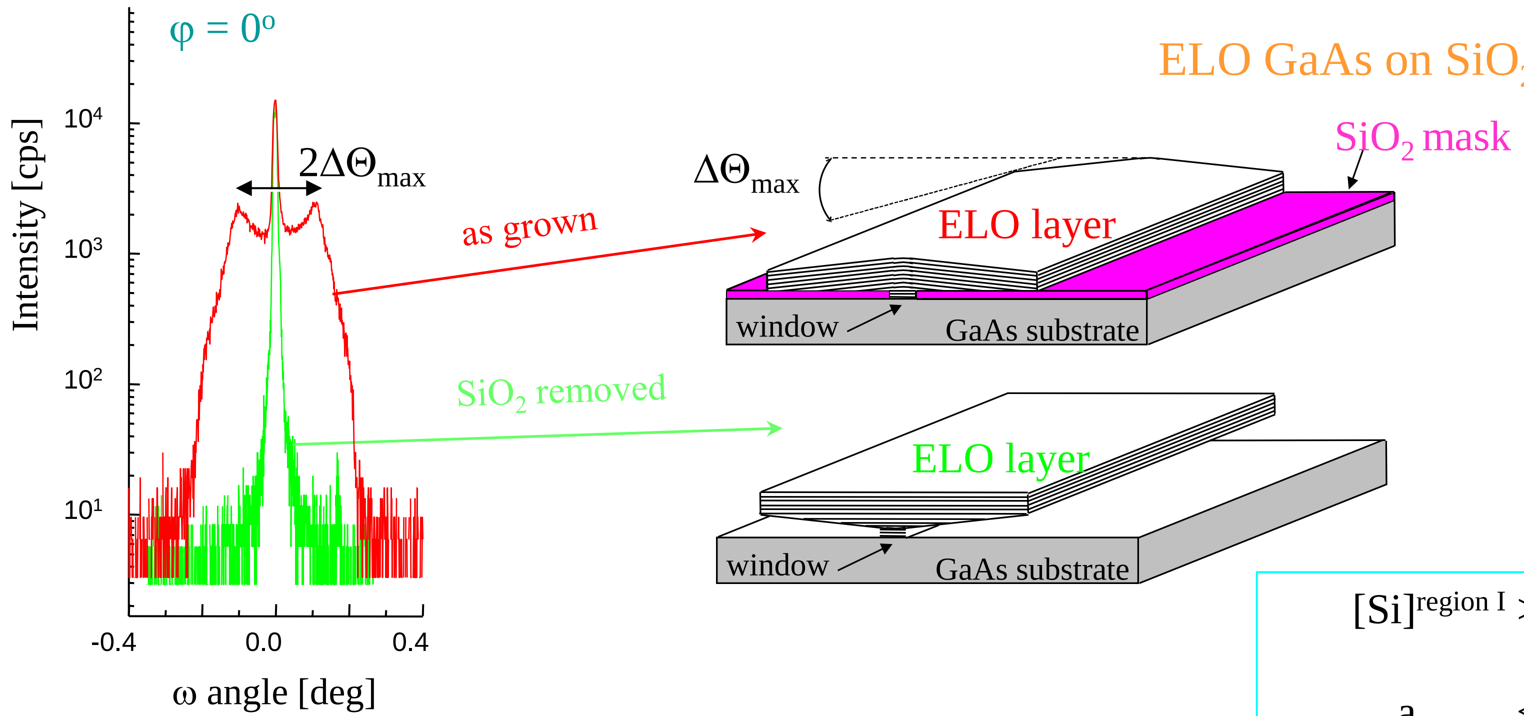


shape of (001) GaAs planes



Bending of ELO layers

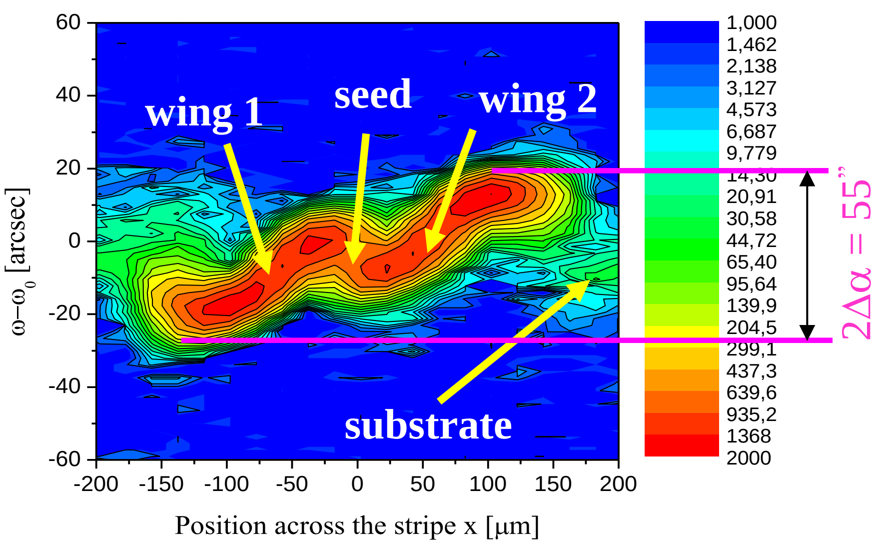
ELO GaAs on SiO_2-coated GaAs

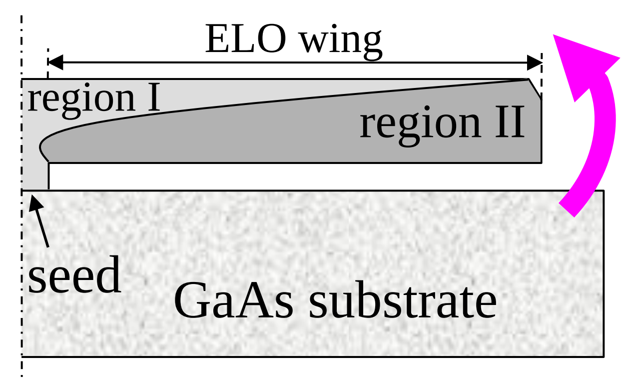


$[Si]^{region\ I} > [Si]^{region\ II}$

$a_{region\ I} < a_{region\ II}$

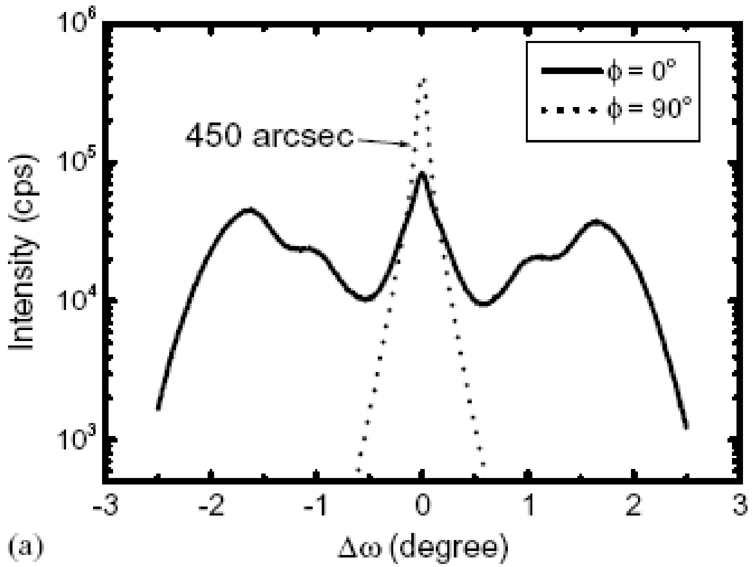
upwards bending of the wing





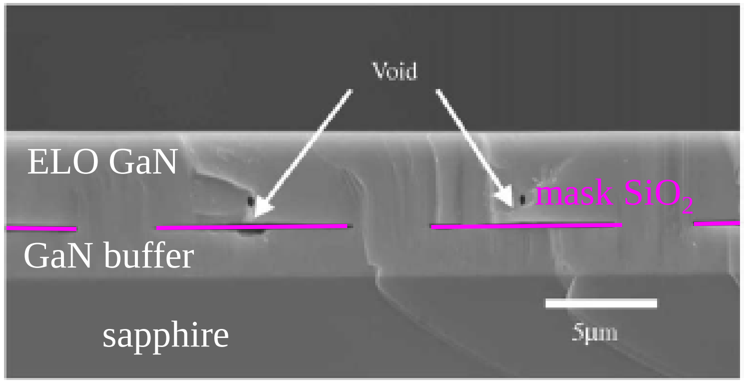
Residual bowing due to nonuniform doping

Bending of ELO layers – common in ELO (GaN, Si, GaAs, etc.)



ELO GaN on sapphire

Kim et al. JCG 2002



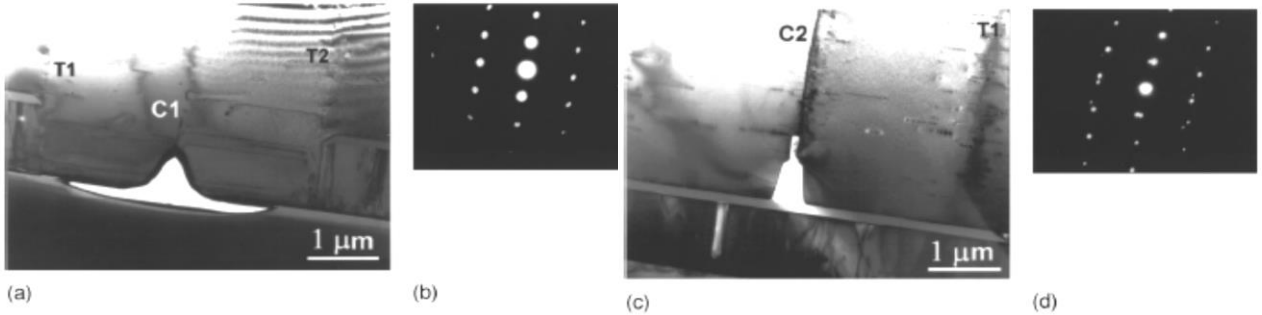
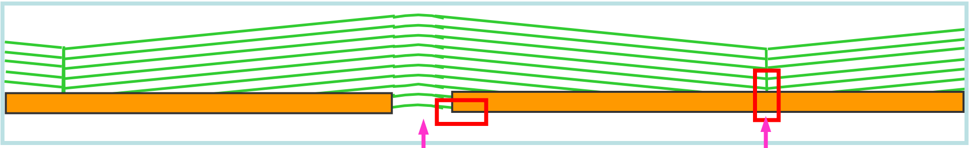


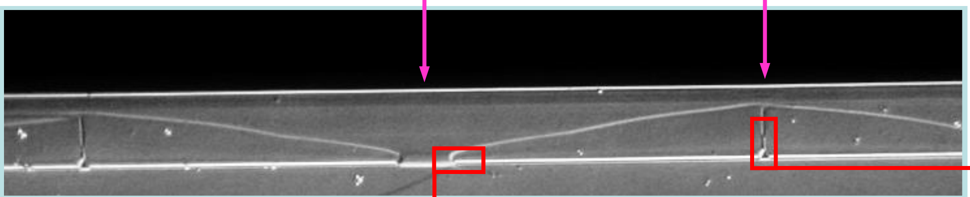
FIG. 2. TEM cross-section images and electron diffraction patterns taken from (a) and (b) window and (c) and (d) mask region.

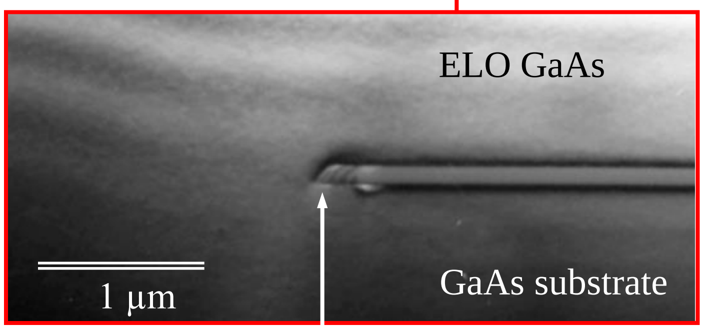
- tilt angle and tilt direction from electron diffraction in TEM
- synchrotron XRD

Coalescence of ELO stripes



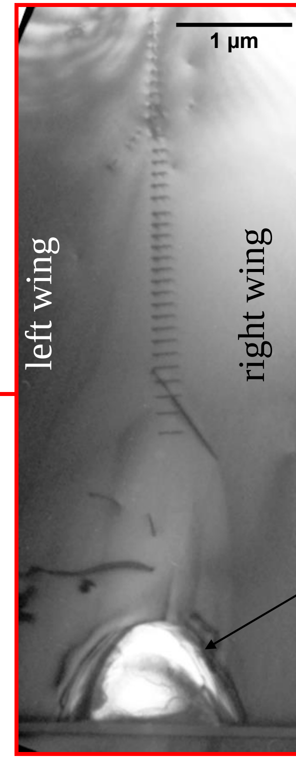
growth window   front of coalescence





no dislocations
above the mask edge

low angle grain boundary



void

SiO_2 mask

GaAs substrate

Zytkiewicz et al. JAP 2007

<u>Similar effect in:</u>

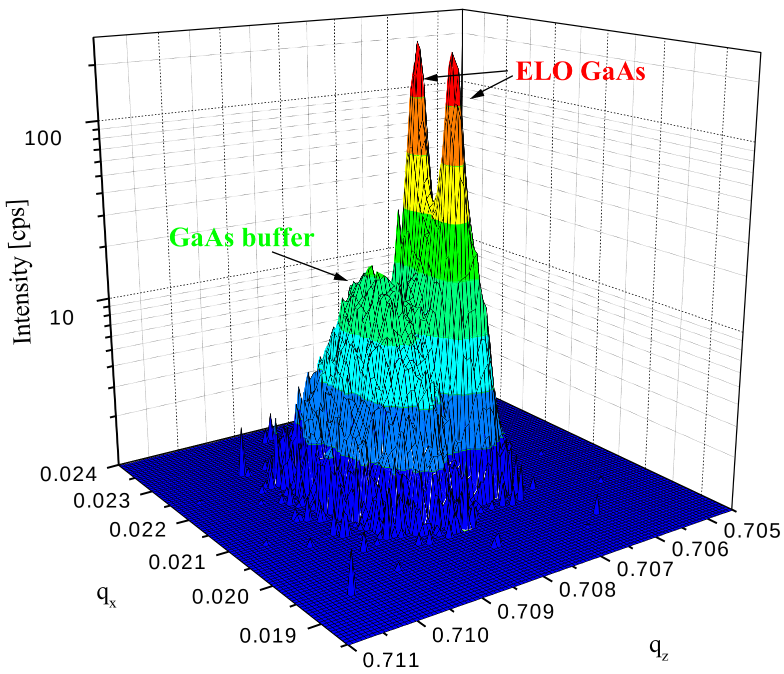
ELO Si on Si - Banhart et al. Appl. Phys. 1993

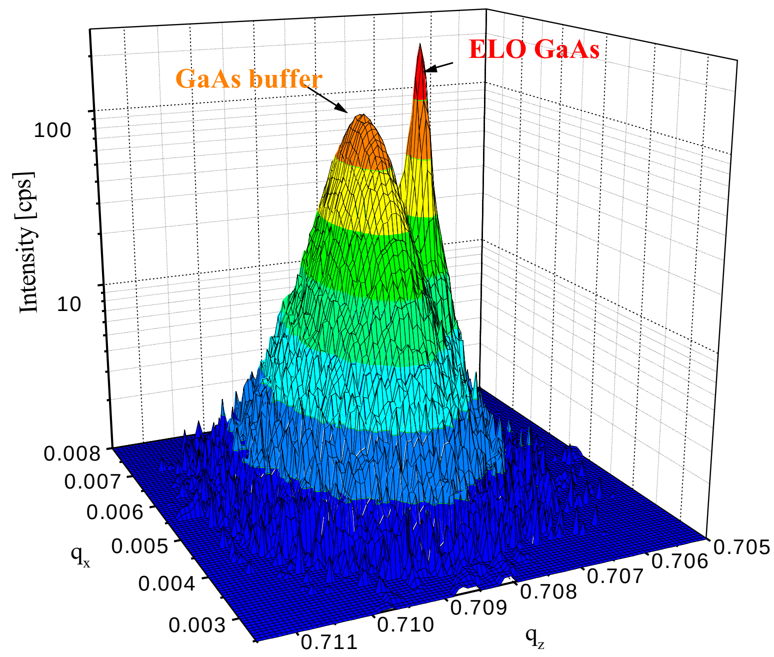
ELO GaN on sapphire - Sakai et al. APL 1998

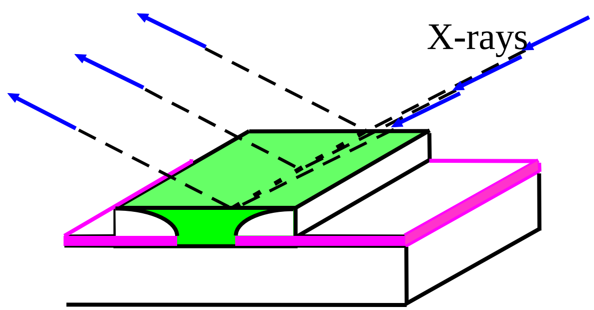
PE GaN on sapphire - Chen et al. APL 1999

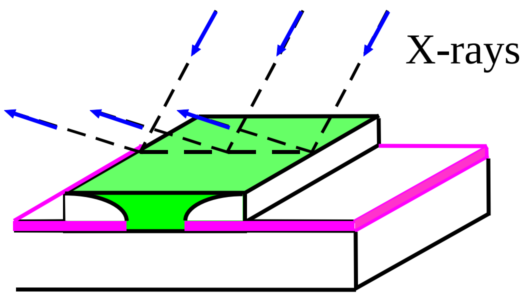
.....

Thermal strain in ELO structures (GaAs/SiO_2/GaAs/Si)









Thermal strain in ELO structures (GaAs/SiO_2/GaAs/Si)

Zytkiewicz et al. APL 1999

Our model:

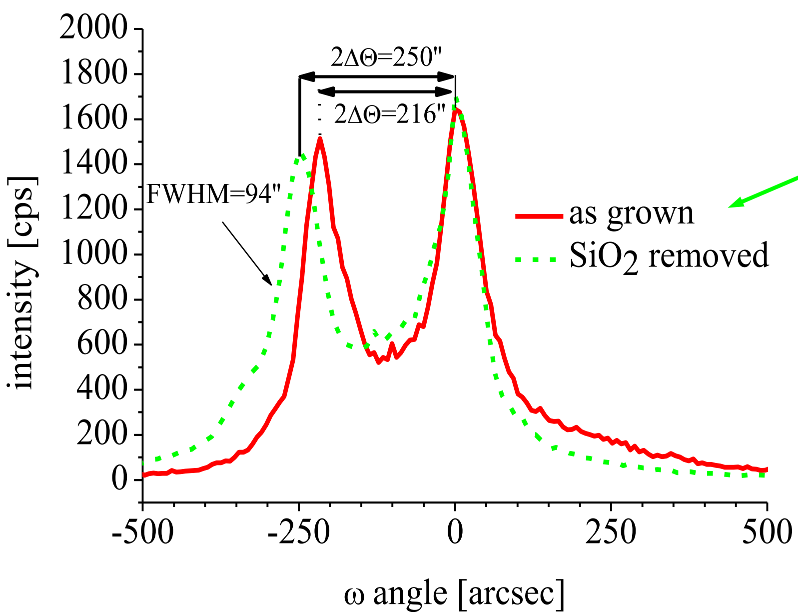
direction of tilt ⟷ sign of thermal strain in the buffer

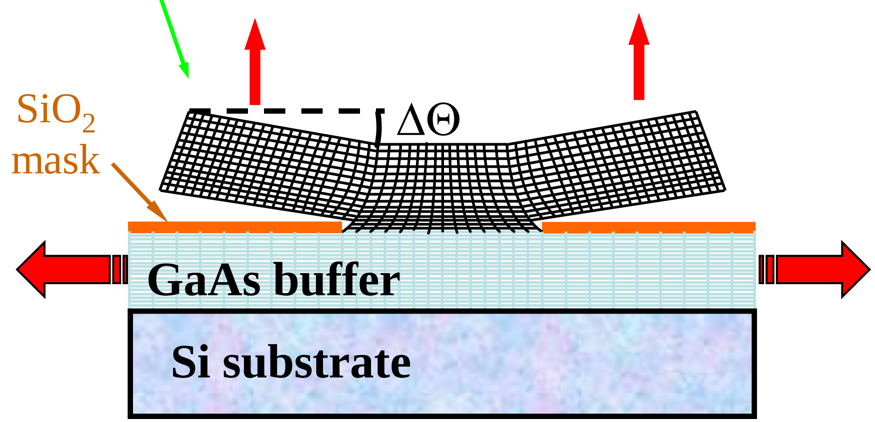
ELO GaAs/Si:

- wings hanging over the SiO_2 mask (no mask-induced tilt)
- wings tilted upwards

GaAs/Si	GaN/sapphire
$\alpha_{GaAs} > \alpha_{Si}$	$\alpha_{GaN} < \alpha_{sapphire}$
tension in GaAs buffer	compression in GaN buffer
upwards tilt	downwards tilt

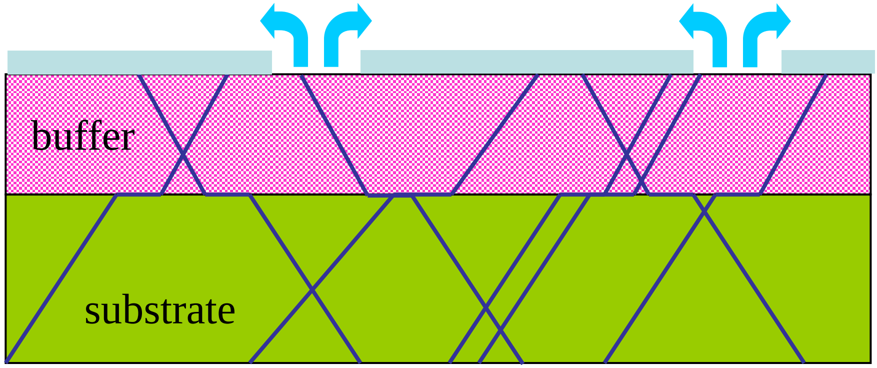
Fini et al. Appl. Phys. Lett. 2000



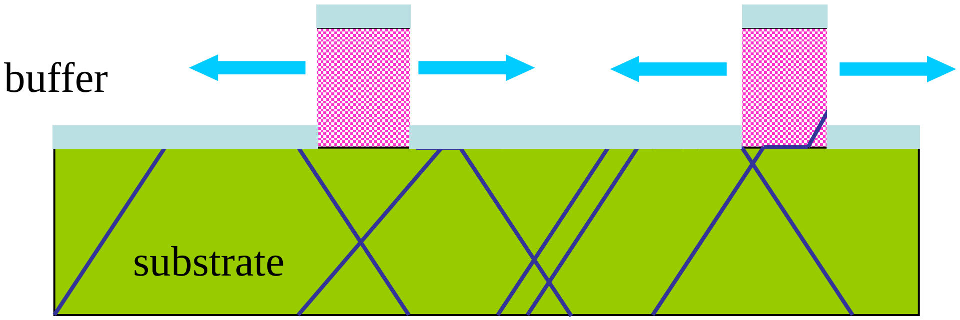


Another ELO concepts (e.g. Pendeo-epitaxy)

Epitaxial Lateral Overgrowth



New concept

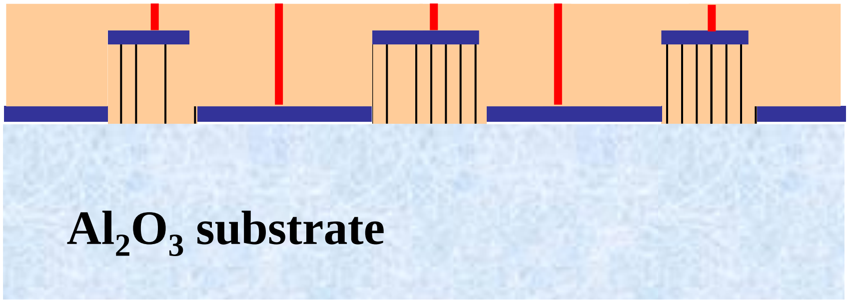


Pendeo-epitaxy

pendeo - "hanging on"
"suspending from"

™ Nitronex Corp., Raileigh,
North Caroline University

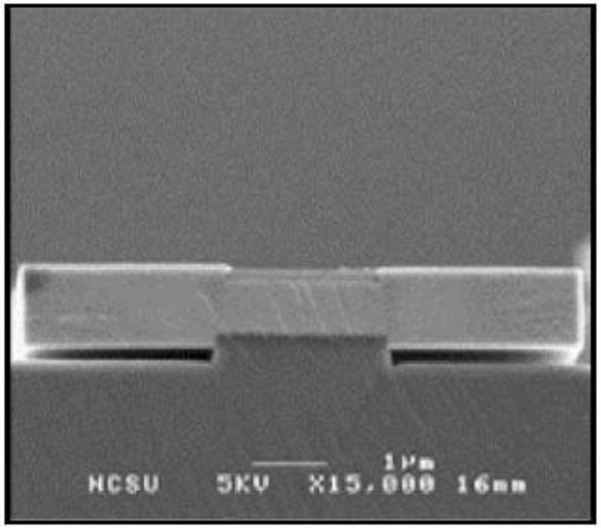
PE GaN



GaN buffer

mask

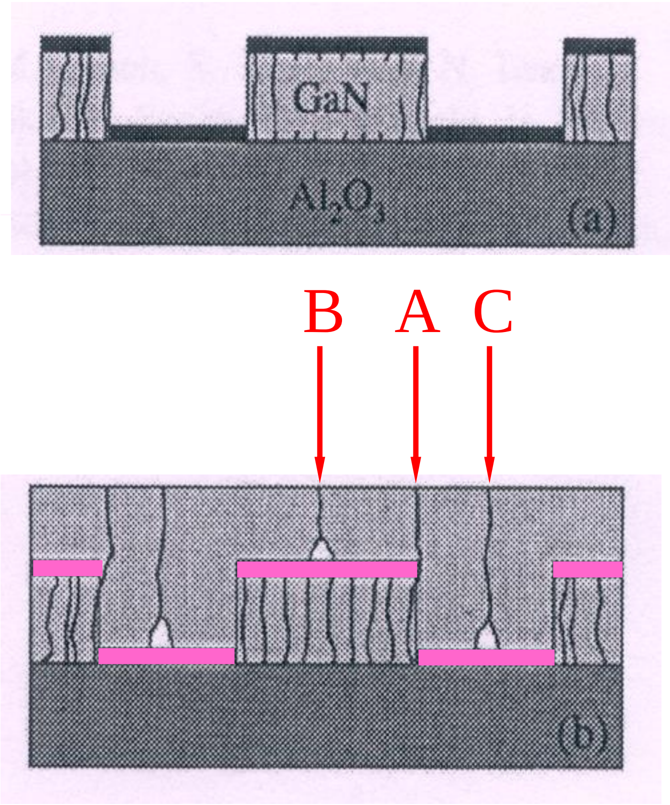
Davis et al. JCG 2001



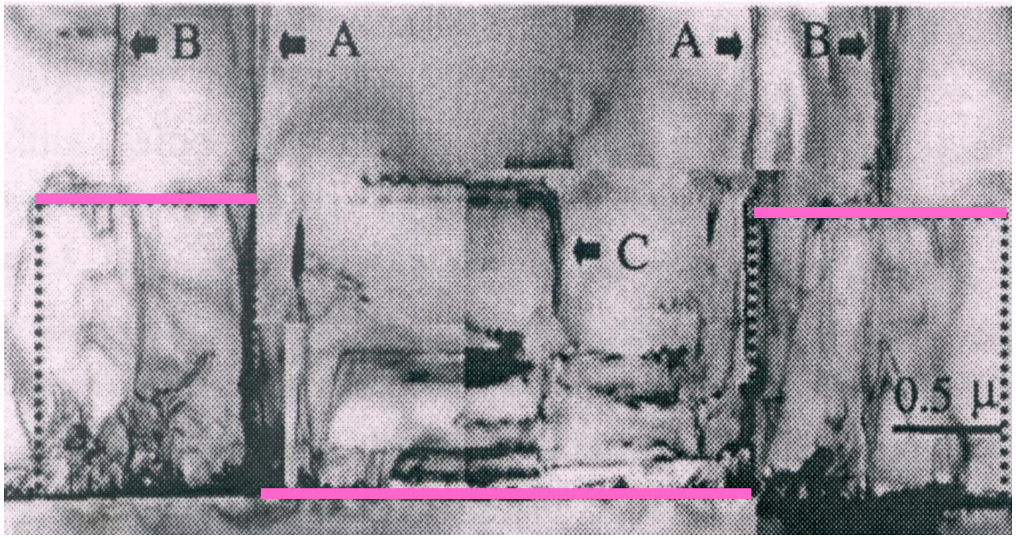
PE vs. ELO: reduction of TD density over the whole wafer within one PE process

Pendeo-epitaxy

Chen et al. APL 1999



TEM

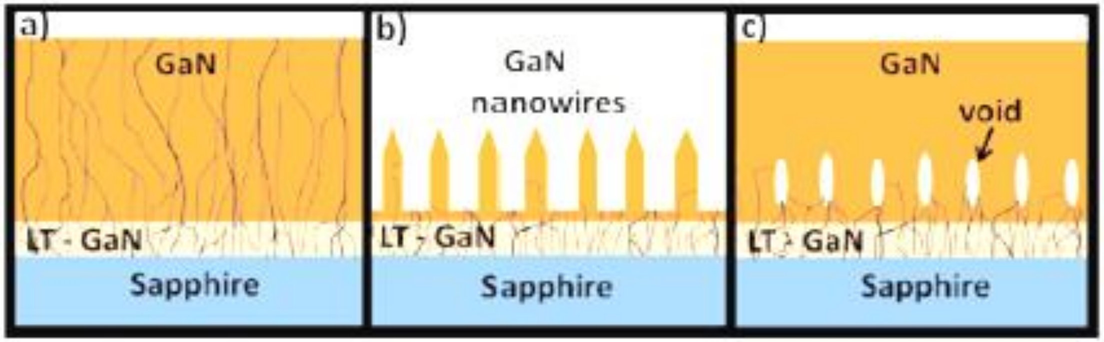


Advantage: maskless versions of PE possible for GaN on SiC or SiC-coated Si

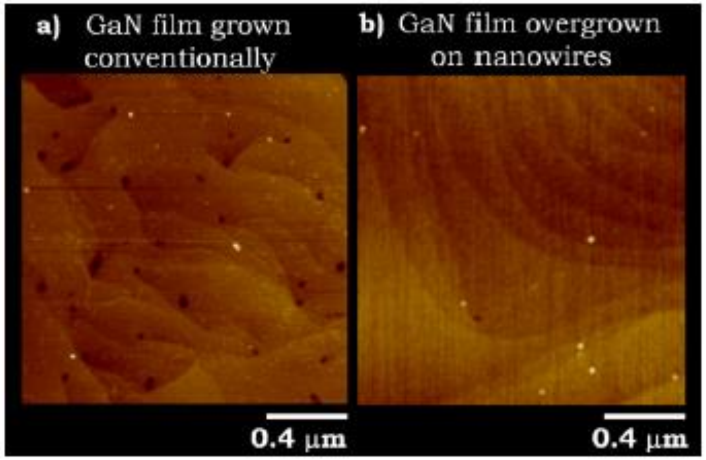
Strittmatter et al. APL 2001; Davis et al. JCG 2001

EVA – Embedded Void Approach

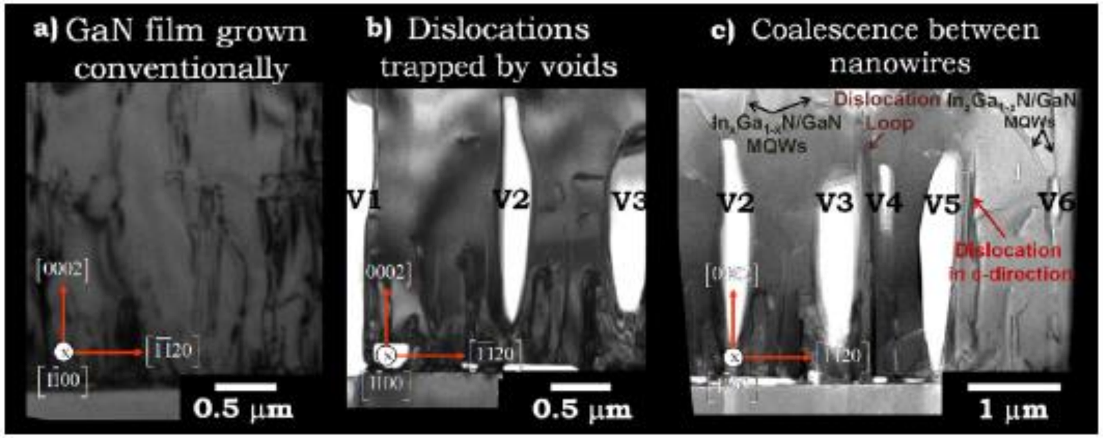
Frajtag et al. APL 2011 ***98*** *023115*



2.1x10^{9} cm^{-2} 3.9x10^{7} cm^{-2}

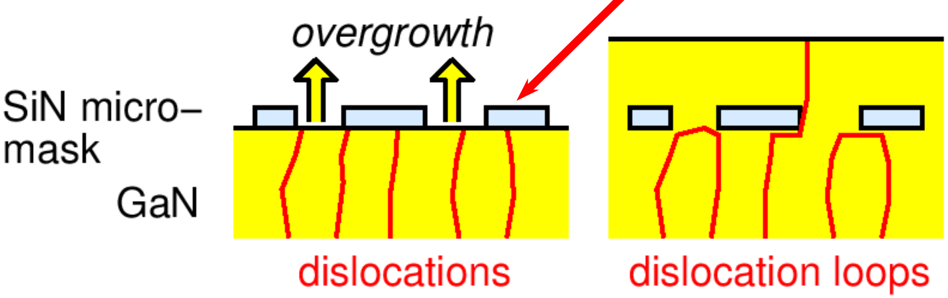


AFM



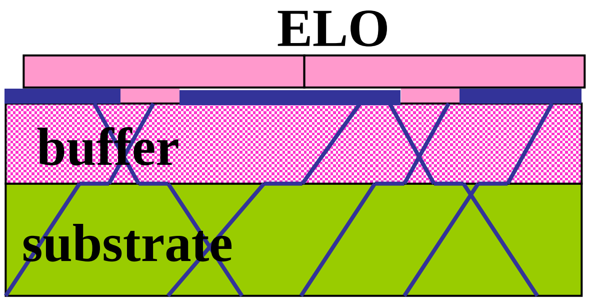
TEM

"random" mask (SiN coverage below 1 ML)



S. Tanaka *et al.*, Jpn. J. Appl. Phys. **39**, L831 (2000)

ELO summary



a tool for fabrication of low-dislocation density epilayers on heavily dislocated substrates

take from the seed info on crystal lattice; do not take defects!!!

ELO – all lattice mismatch-induced problems solved?

Achievements:

1. significant reduction of dislocation density in lattice-mismatched heterostructures
2. easier elastic relaxation of thermal strain

Problems:

1. interaction of ELO layers with the mask; bending
2. generation of defects at the front of coalescence