Атомно-слоевое осаждение для роста соединений AIIIBV на кремнии

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Outline

- Motivation
- PE-ALD GaP/Si interface properties
- Thermal annealing of PE-ALD GaP/Si interface (RTA, MOCVD)
- First MOCVD growth on PE-ALD GaP/Si templates
- Conclusions

Motivation

Integration of III-V with Si

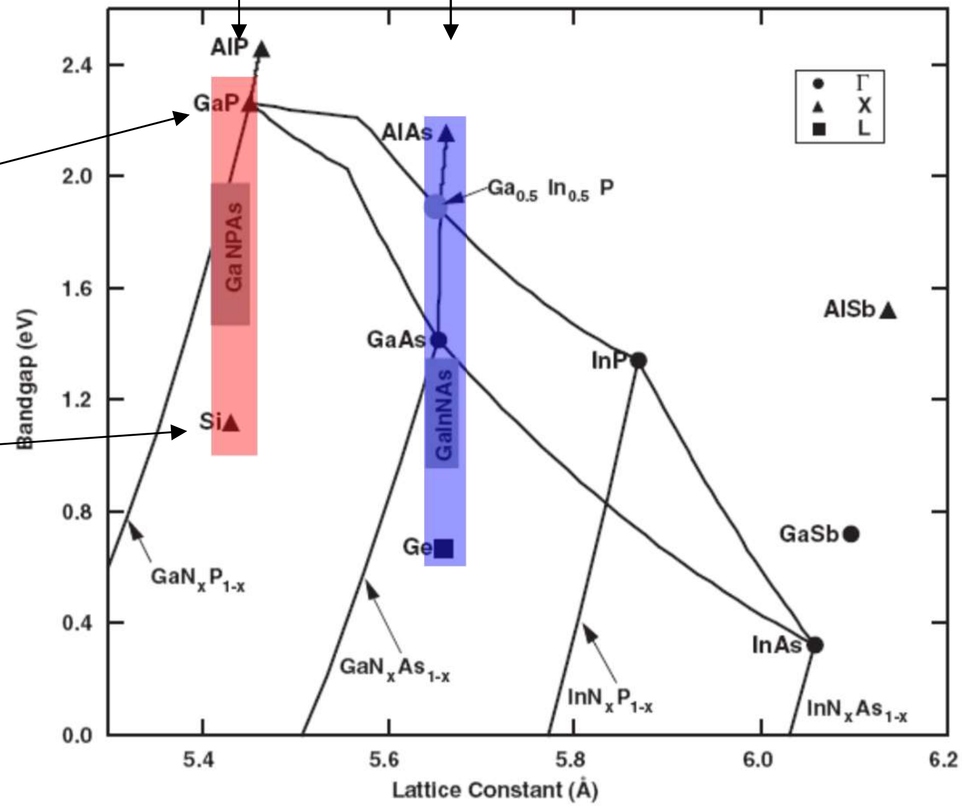
Optoelectronic devices grown on Si

Multijunction solar cells on Si substrate

GaP (E_g 2.26 eV) has the smallest lattice mismatch beyond III-V binary compounds (<0.4%) to Si

- nucleation layer for III-V multijuction solar cell grown on Si substrate
- appropriate wide gap emitter for Si based sub-cell

GaPN(As)/Si GaInP/GaAs/Ge



J F Geisz and D J Friedman Semicond. Sci. Technol. **17** (2002) 769–777

Motivation

Epitaxial growth of GaP requires high temperature

Pre-treatment for Si surface deoxidation and reconstruction **High T 900°C**

Growth **600-750 °C**

Significant lifetime degradation of Si wafers after annealing in

MOVPE chamber

R. Varache et al. // Energy Procedia 77 (2015) 493-499

MBE chamber

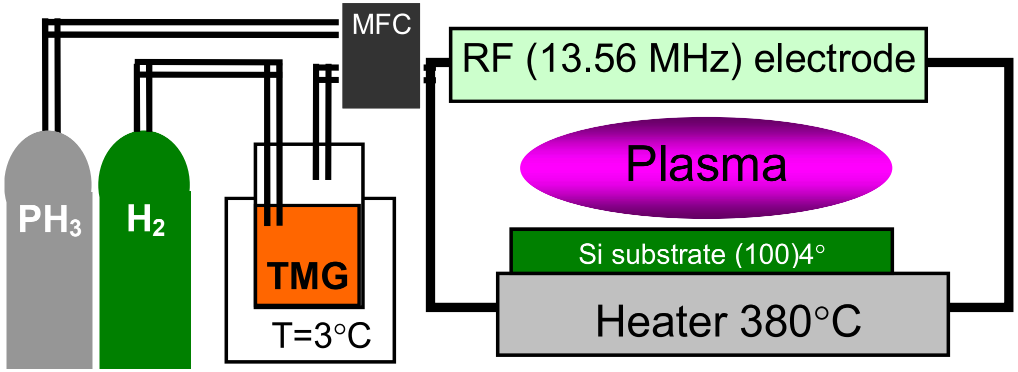
L. Ding et al. // Energy Procedia 92 (2016) 617

Low temperature nucleation process, which provides 2D growth?

Atomic layer deposition (ALD)

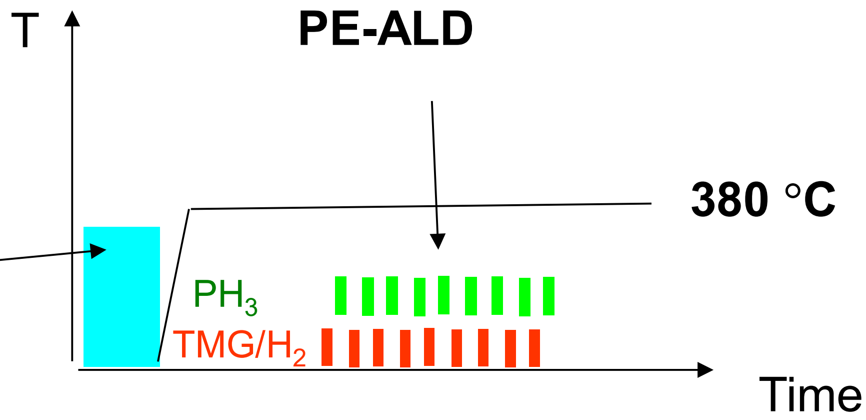
Low Temperature Plasma enhanced atomic layer deposition (PE-ALD)

Oxford Plasmalab 100 PECVD

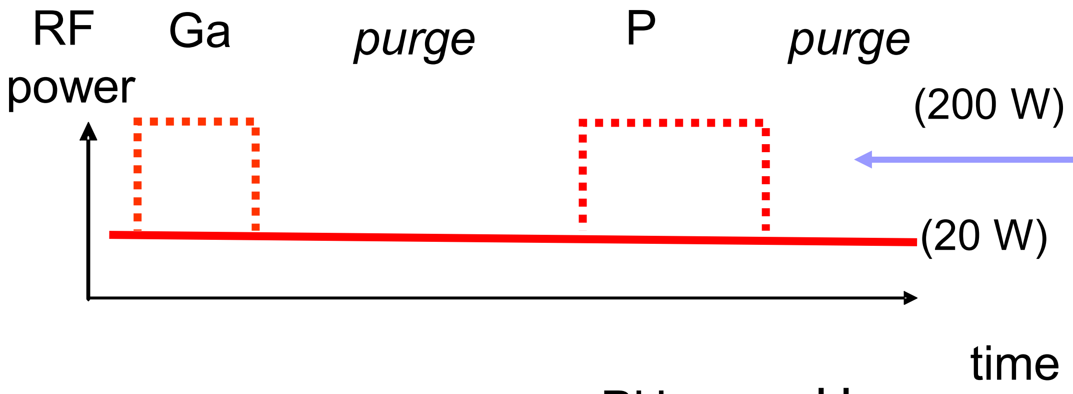


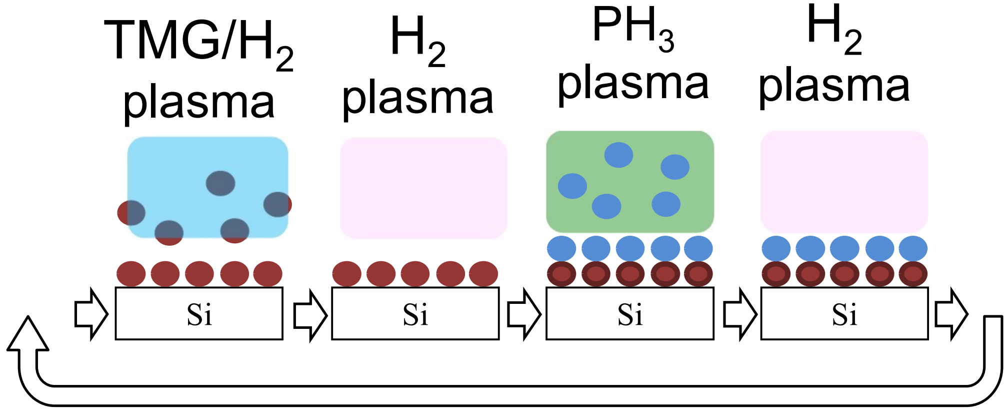
GaP layers were grown on Si (100) 4° cut off substrates at **T=380 °C**

HF Deoxidation and H-passivation

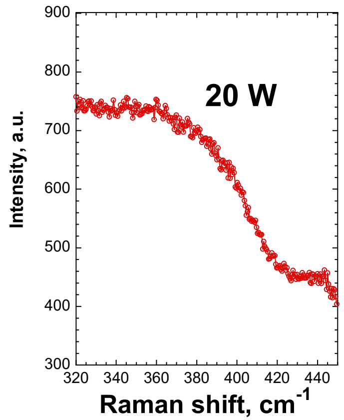


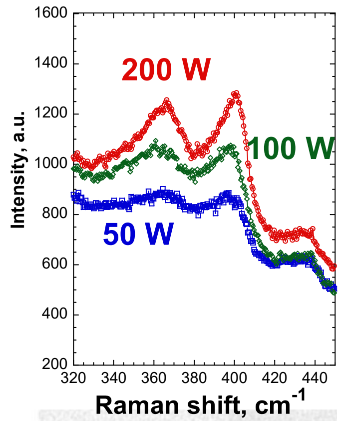
Continues H_2 plasma
(pseudo ALD mode)

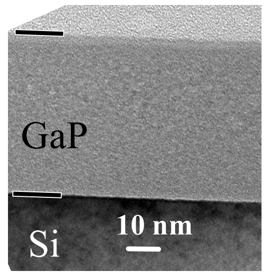


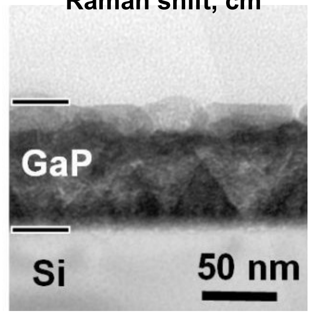


Increase of the RF power pulse during deposition step leads to **transfer** from **amorphous** to **microcrystalline GaP** growth





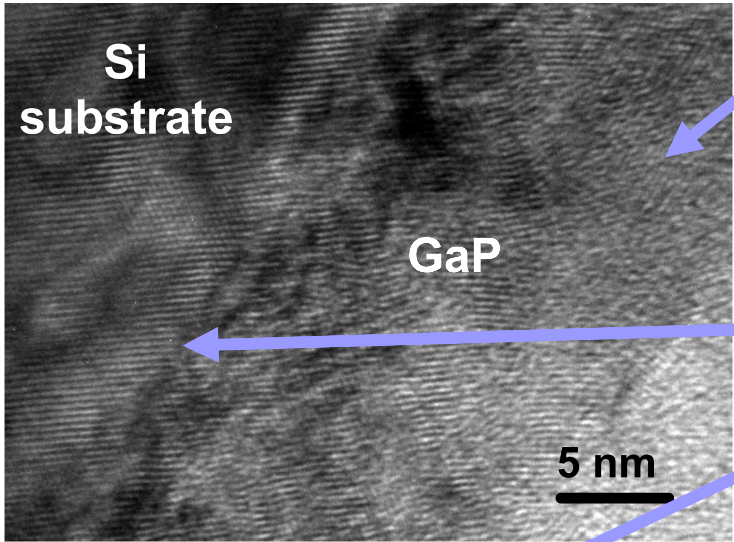




Gudovskikh et.al. //J. Vac. Sci. Technol., A 36 (2018) 21302.

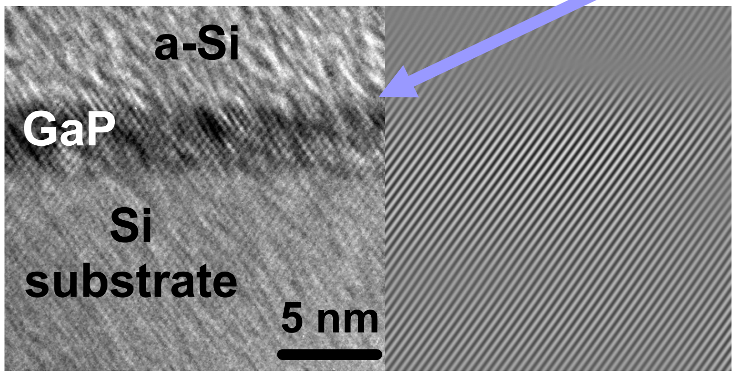
TEM of GaP/Si interface

H_2-plasma process



Microcrystalline structure
of GaP films

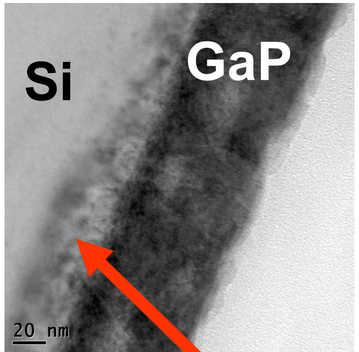
Epitaxial 2D growth
of 3-5 nm GaP on Si substrate



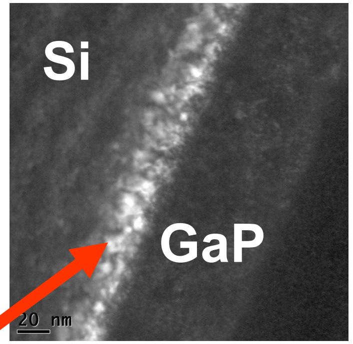
TEM image
of a-Si/epi-GaP/Si

Filtered TEM
image

Bright field TEM

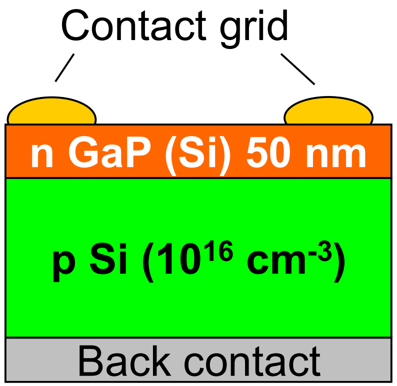


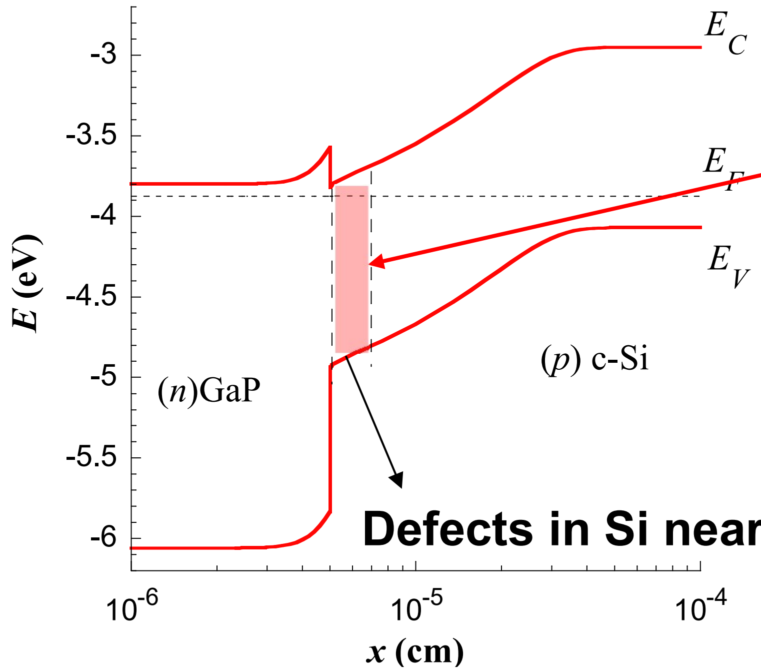
Dark field TEM

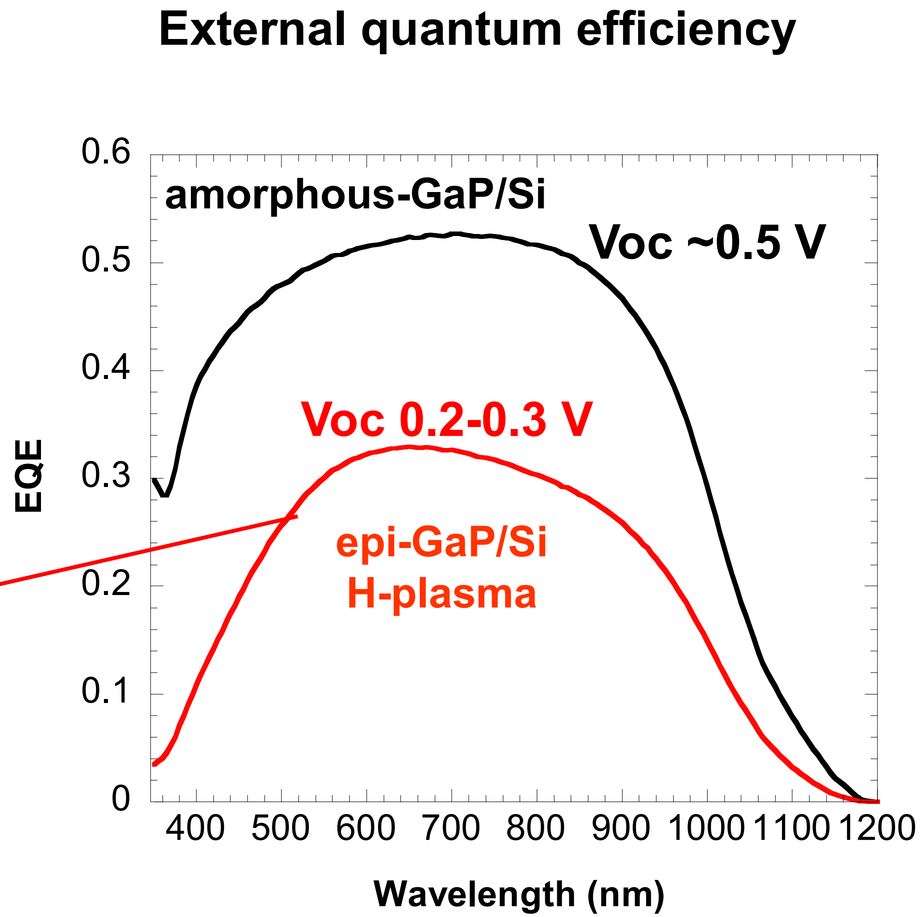


Hydrogen plasma
leads to **damage of Si substrate**
(30-50 nm near to the interface)

Photoelectrical properties of n-GaP/p-Si



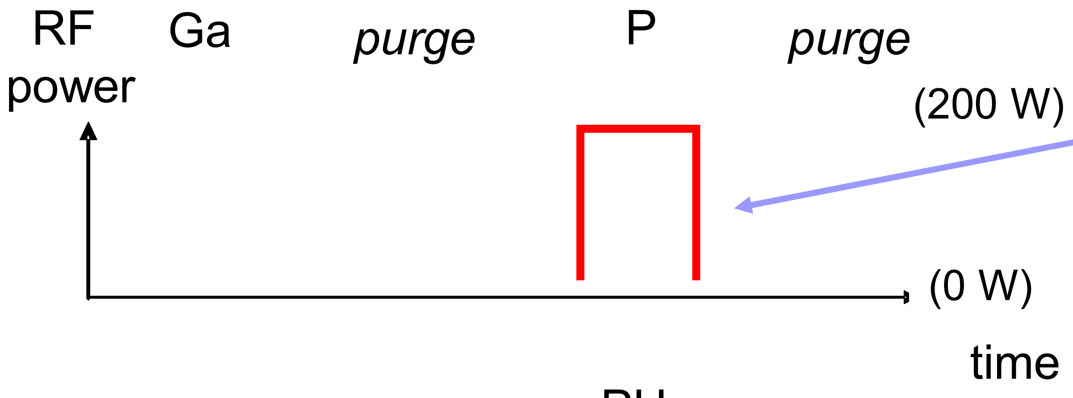




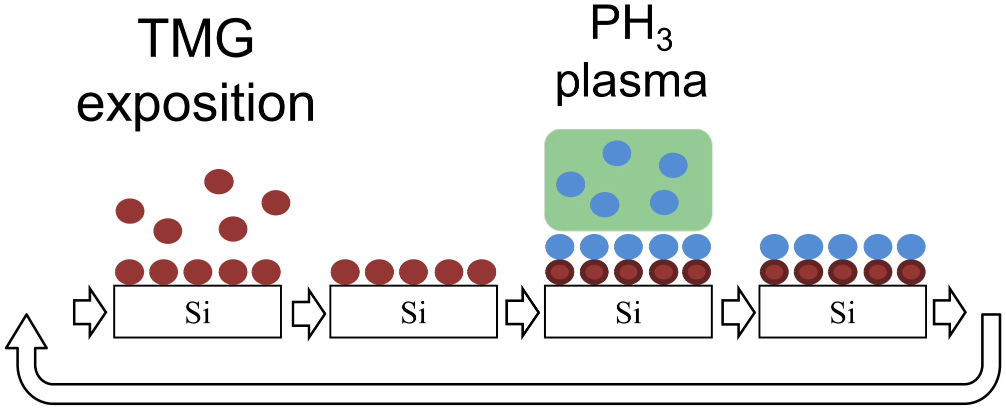
Defects in Si near to GaP/Si interface lead strong recombination losses

Gudovskikh et.al.// Phys. Status Solidi A (2018) 1800617

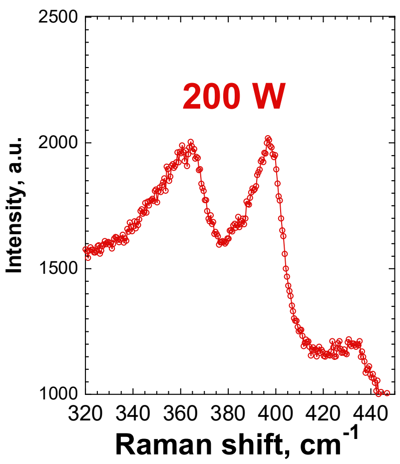
No H_2 plasma (real ALD mode)

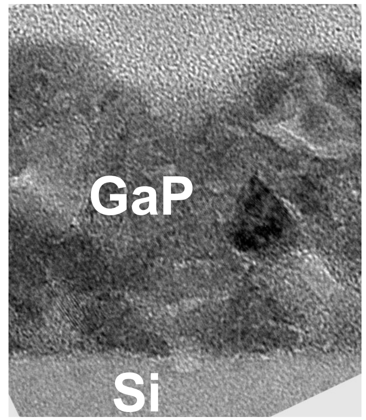


RF power pulse is used for PH_3 decomposition only (380 °C is not enough)



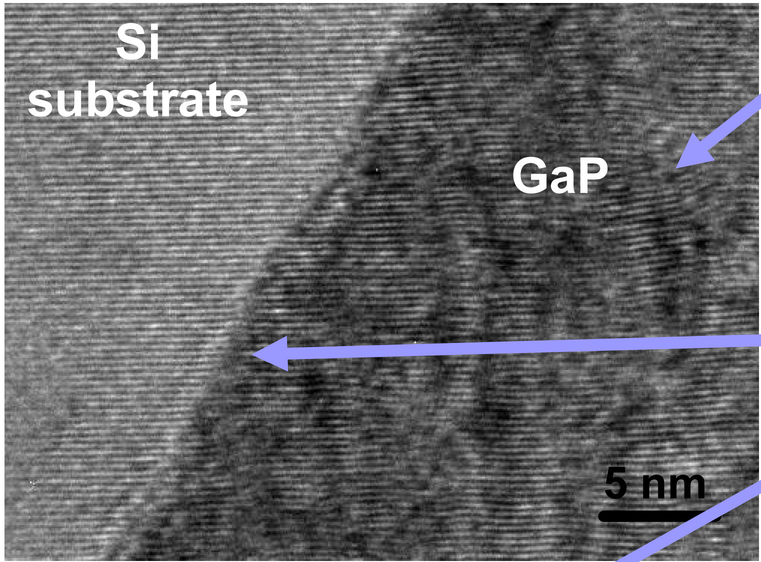
microcrystalline GaP growth





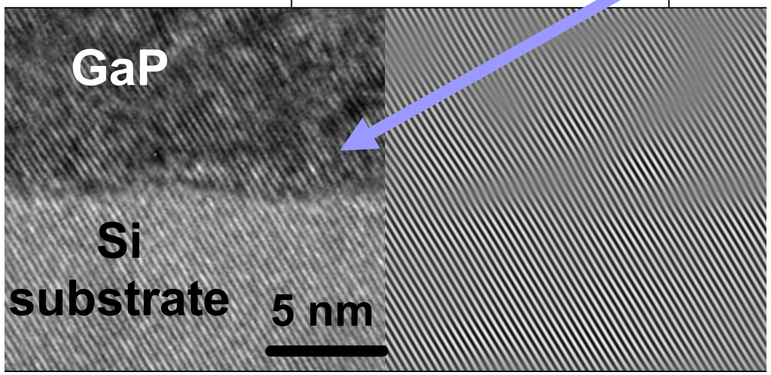
TEM of GaP/Si interface

No H_2-plasma process



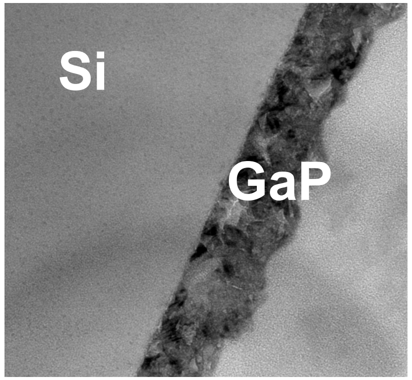
Microcrystalline structure
of GaP films

Epitaxial 2D growth
of 3-5 nm GaP on Si substrate

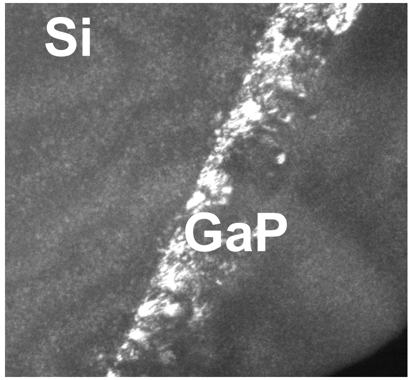


Filtered TEM image

Bright field TEM

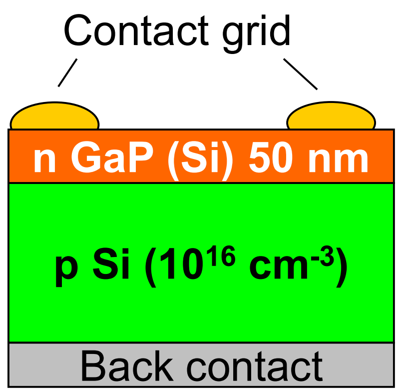


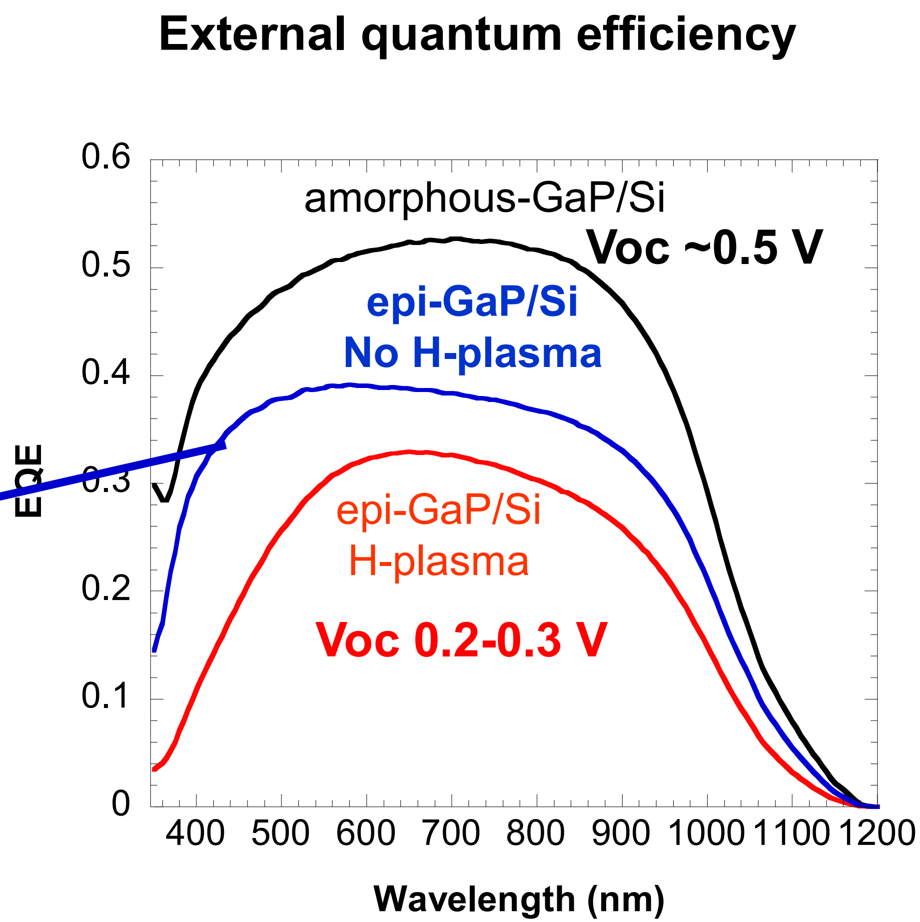
Dark field TEM



damage of Si substrate is not observed by TEM

Photoelectrical properties of n-GaP/p-Si



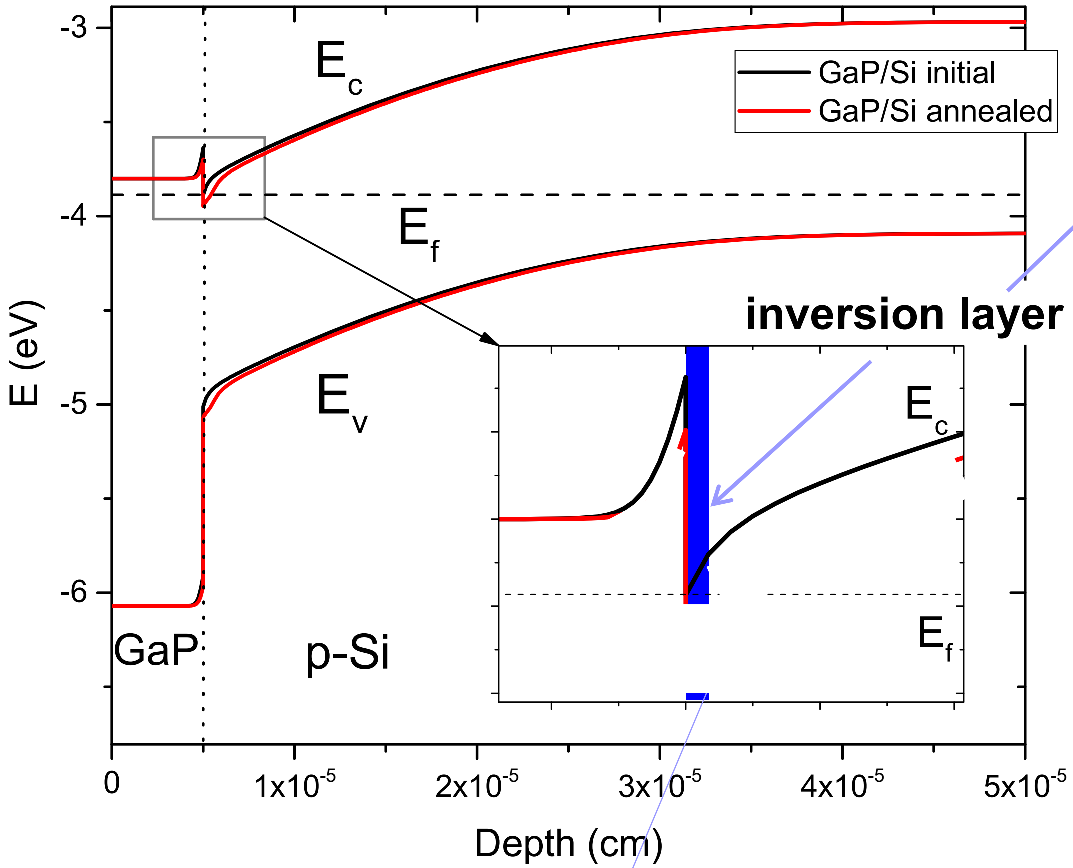


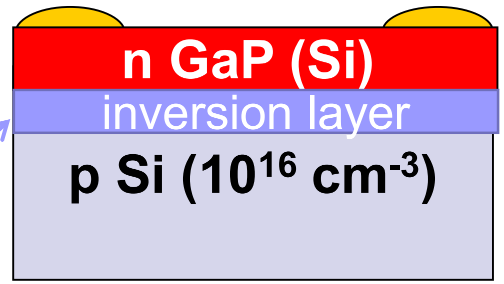
Voc 0.4-0.5 V

Better photoelectrical properties
compared **to H-plasma** process but still
lower compared to amorphous

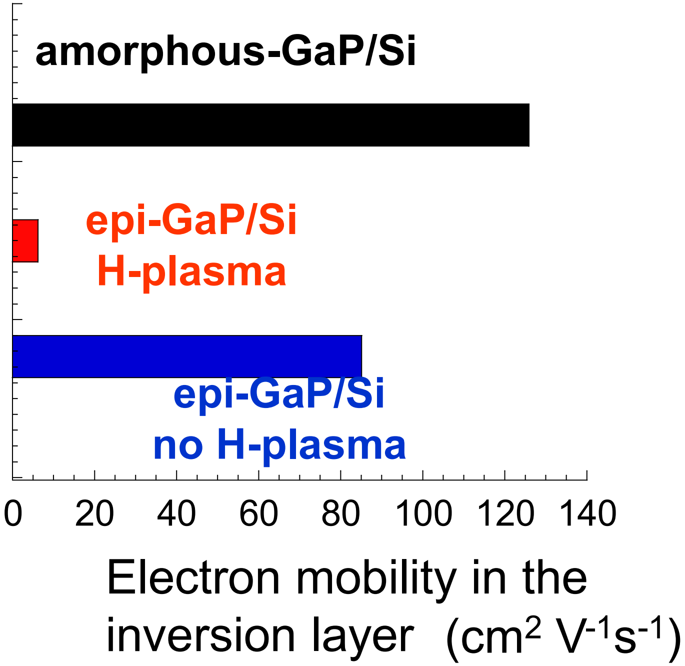
Defects are still created by high power plasma
Presence of hydrogen?

Band diagram of n-GaP/p-Si





Hall effect measurements



Thermal annealing
- Phosphorous diffusion into p-Si
- Structural changing
- Defects creation/annihilation

Influence of thermal annealing

RTA

Jipelec Jet 100

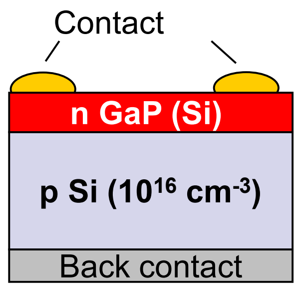
1 min, N_2 environment

amorphous-GaP/Si

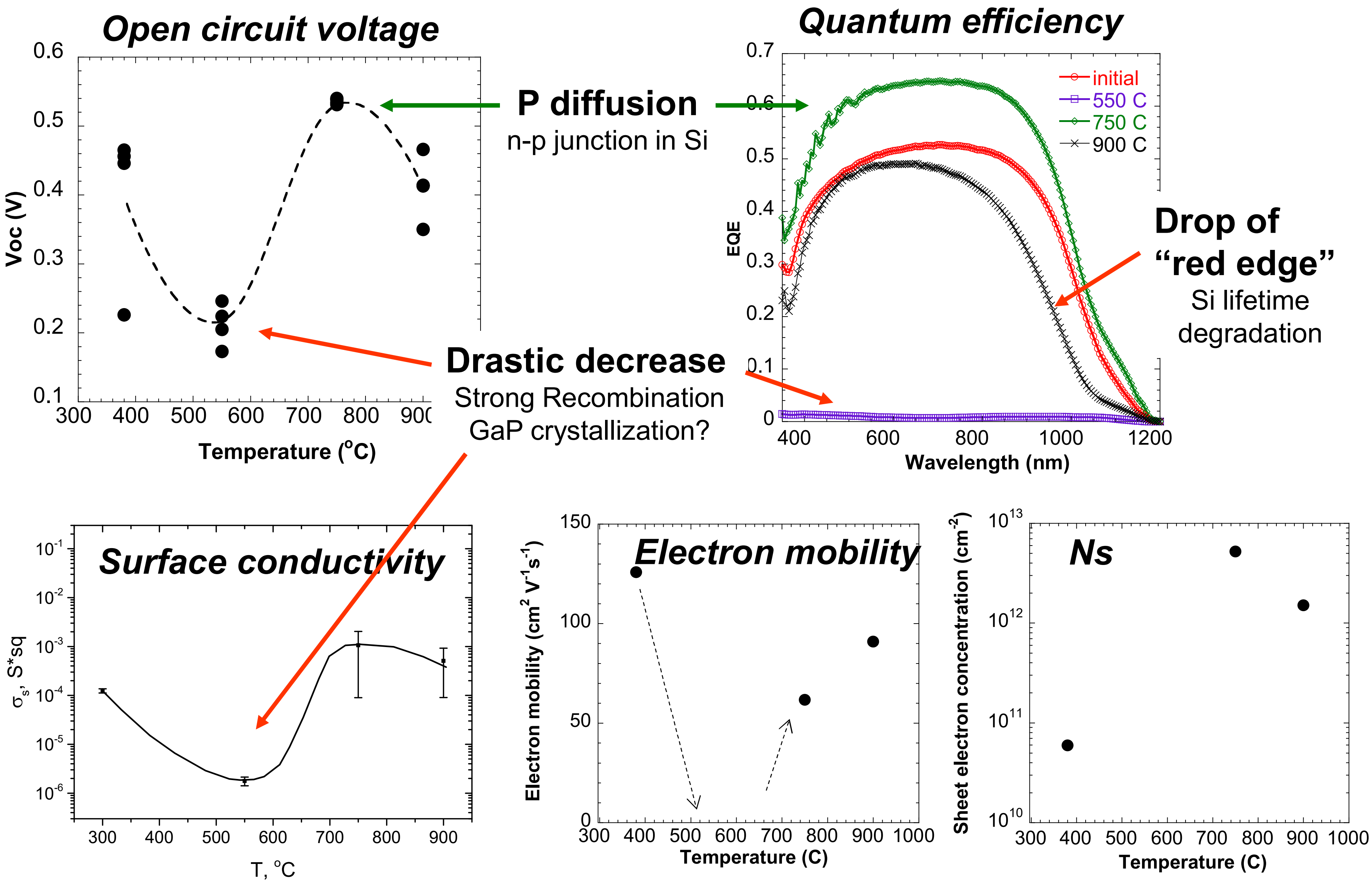
epi-GaP/Si H-plasma

epi-GaP/Si no H-plasma

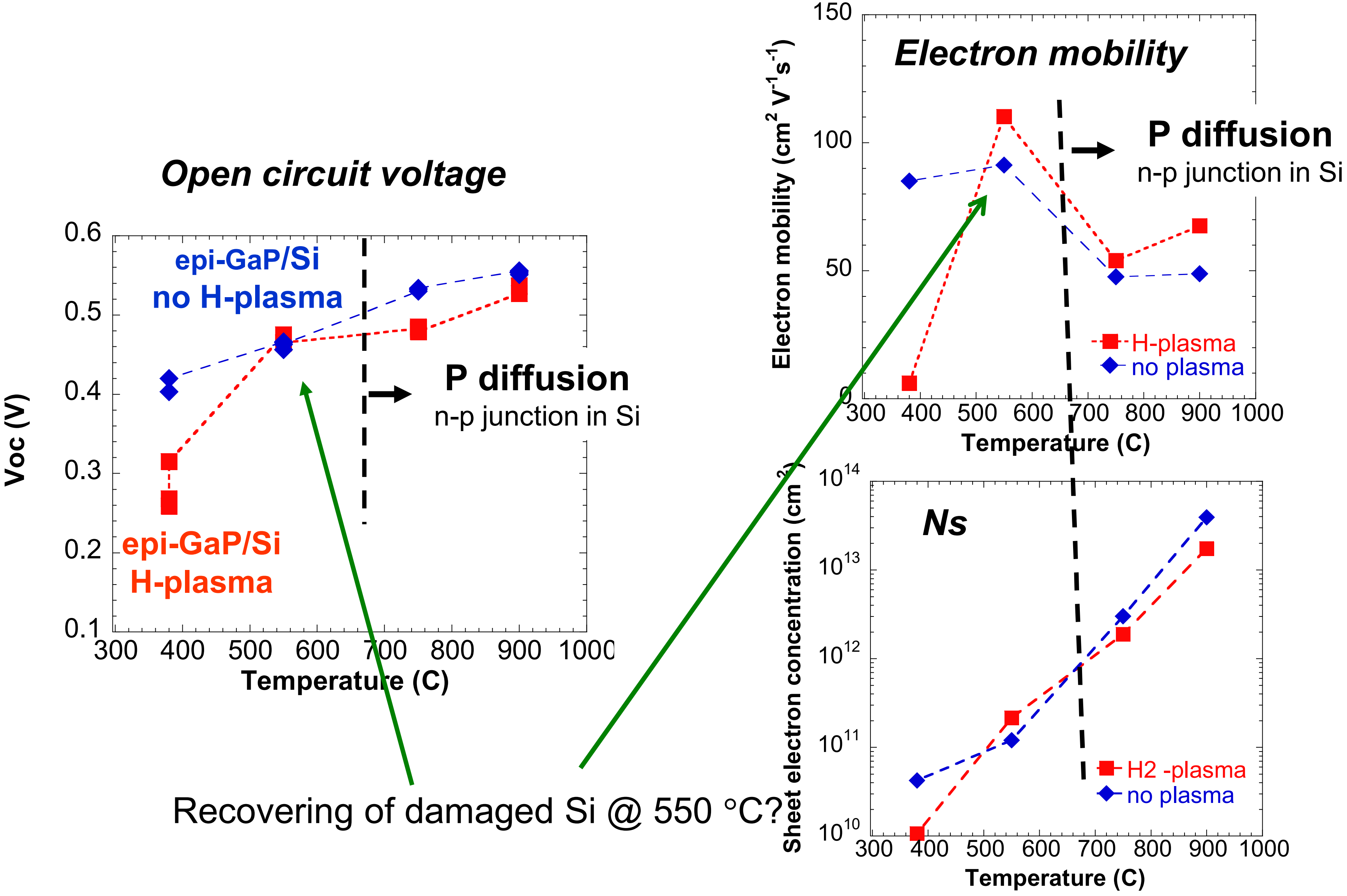
550…900 °C



amorphous-GaP/Si

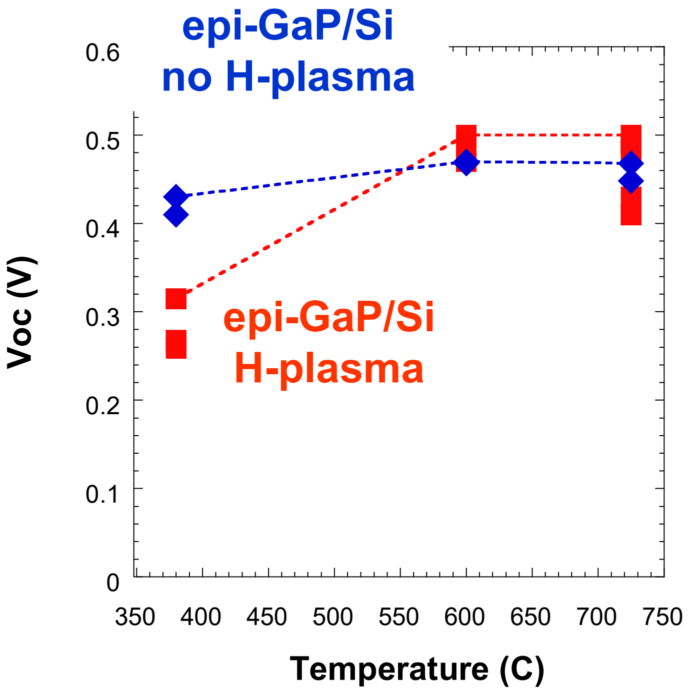


epi-GaP/Si

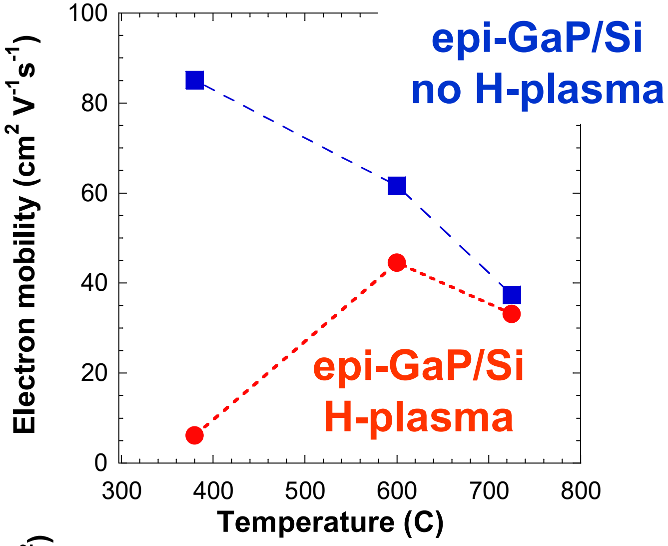


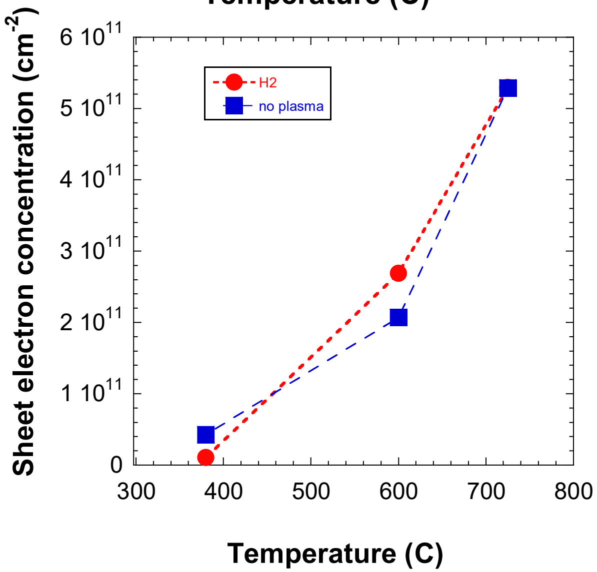
Open circuit voltage
Voc (V)
0.6
0.5
0.4
0.3
0.2
0.1
300 400 500 600 700 800 900 1000
Temperature (C)
epi-GaP/Si
no H-plasma
epi-GaP/Si
H-plasma
P diffusion
n-p junction in Si
Electron mobility
Electron mobility (cm2 V-1s-1)
150
100
50
0
300 400 500 600 700 800 900 1000
Temperature (C)
P diffusion
n-p junction in Si
H-plasma
no plasma
Ns
Sheet electron concentration (cm-2)
10^14
10^13
10^12
10^11
10^10
300 400 500 600 700 800 900 1000
Temperature (C)
H2 -plasma
no plasma
Recovering of damaged Si @ 550 °C?

MOCVD chamber annealing (30 min, PH_3 environment)



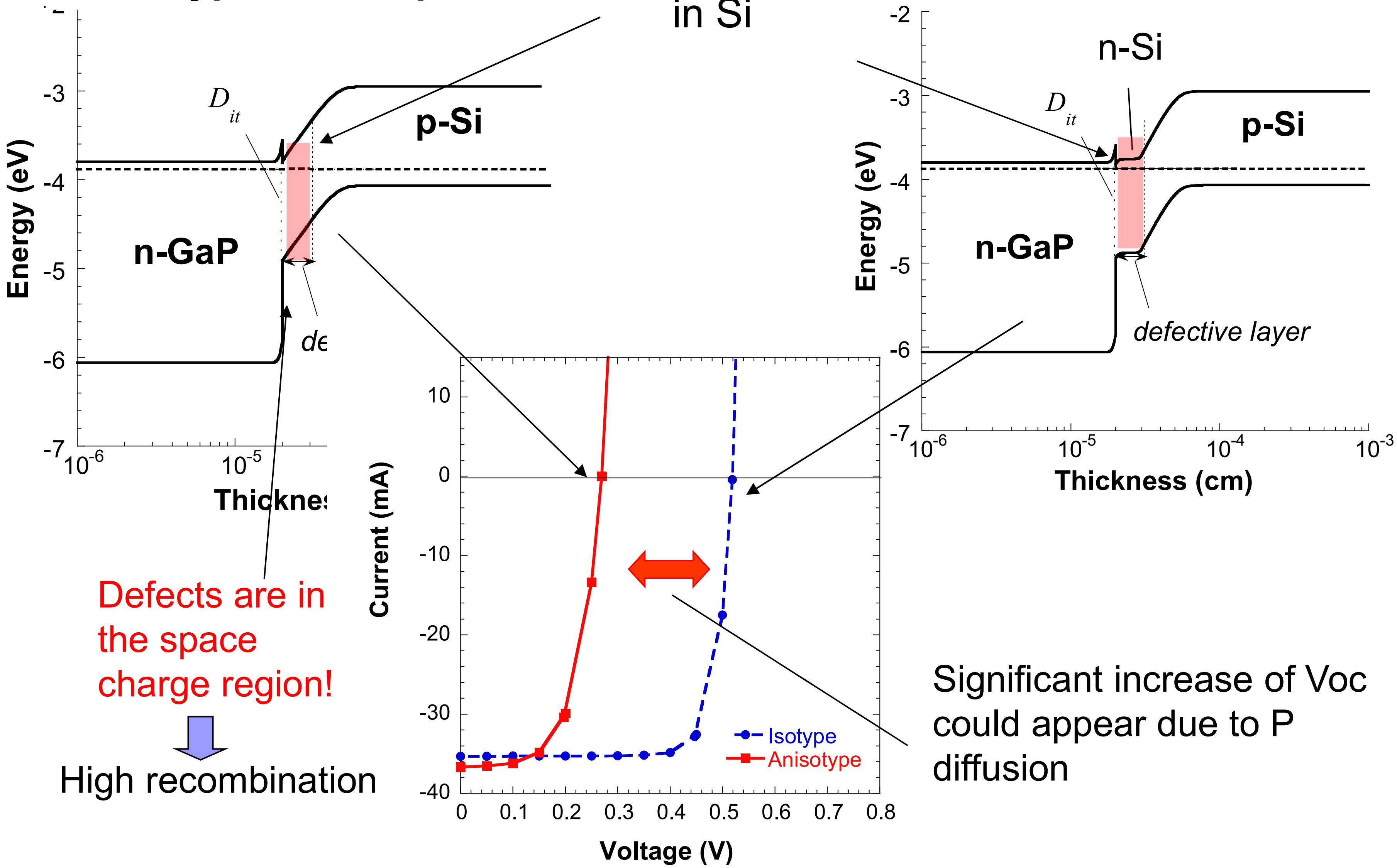
The same trend as for RTA





Simulations

Anisotype n- GaP/p- Si | **Isotype n- GaP/n-p Si**



Defects are in the space charge region!

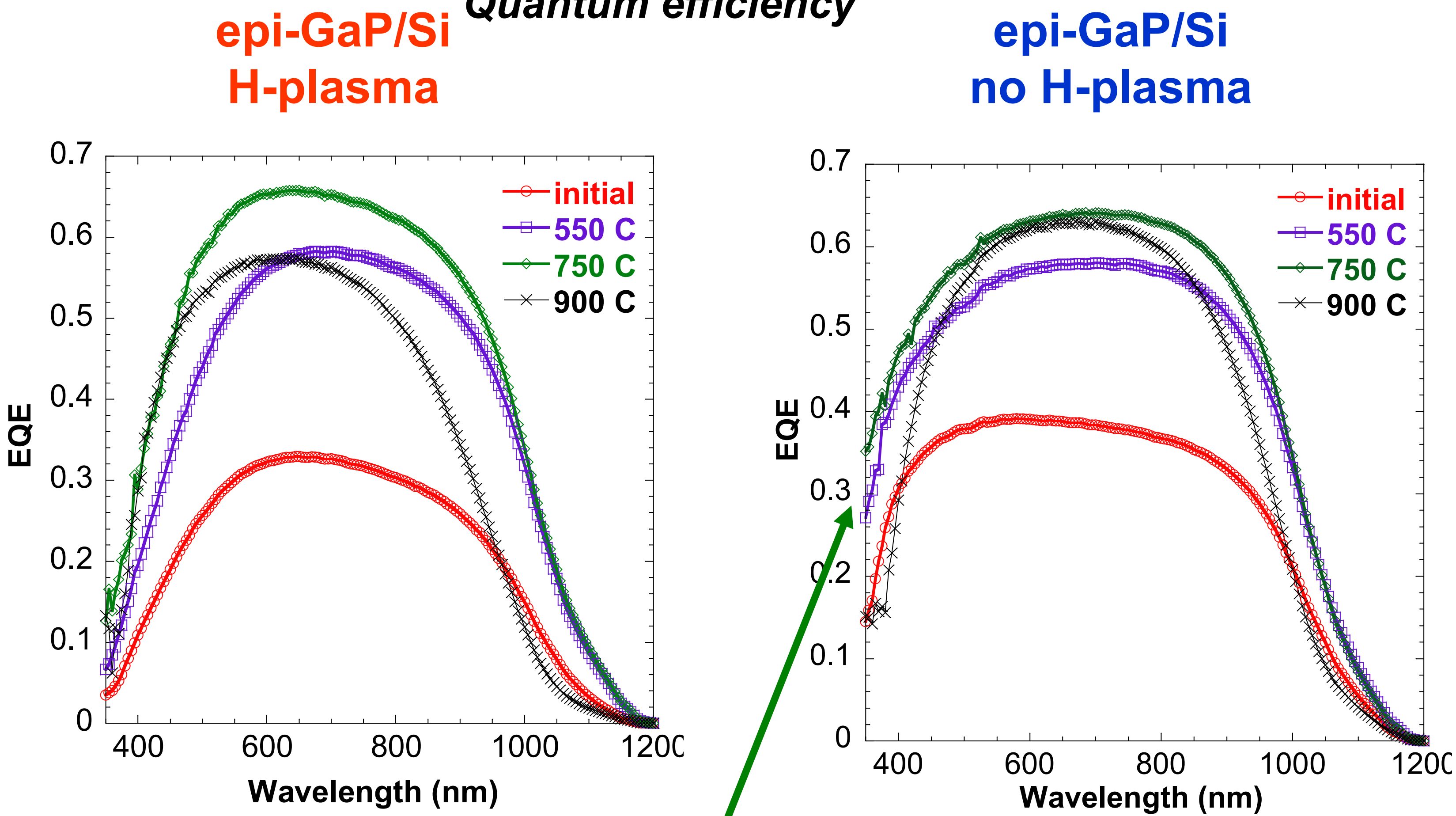
⇩

High recombination

Significant increase of Voc could appear due to P diffusion

epi-GaP/Si

Quantum efficiency



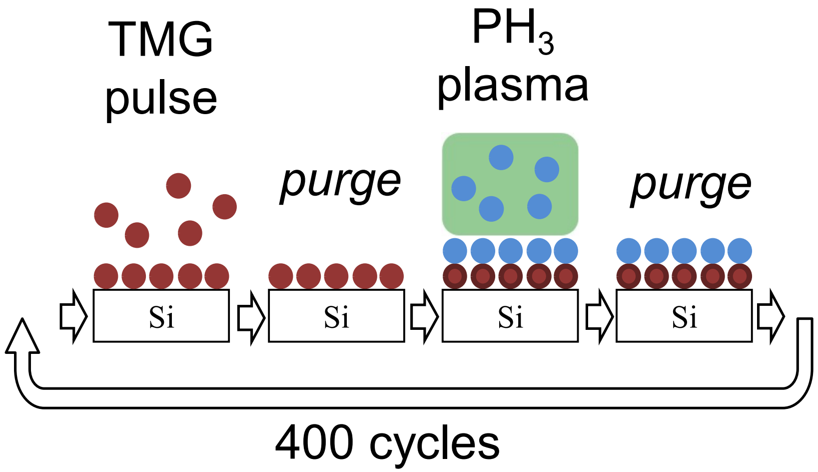
Higher efficiency at short wavelengths after annealing @ 550 and 750 °C

Lower recombination losses ⇨ Lower defect concentration

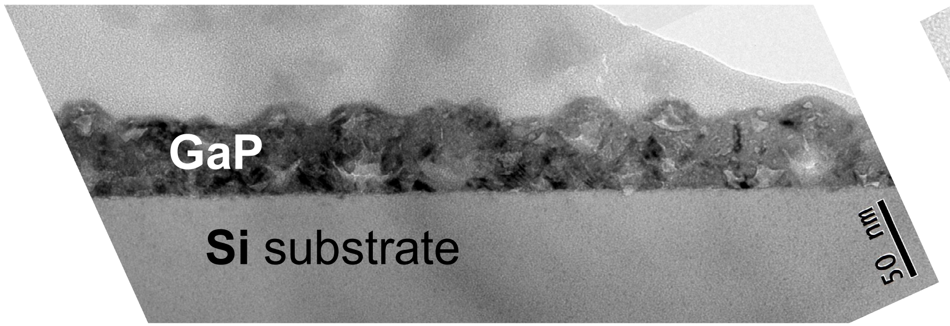
Process without H_2 plasma is preferable!

PE-ALD without H_2 plasma

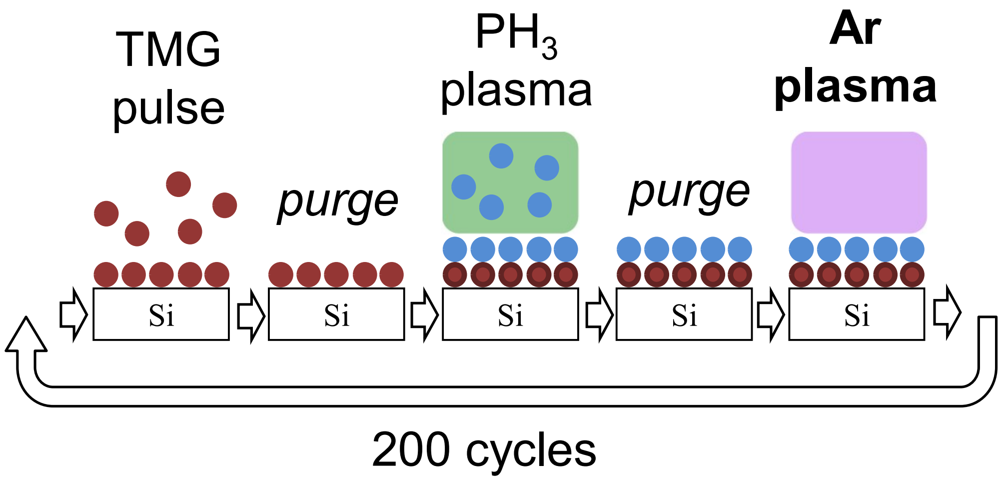
No plasma activation



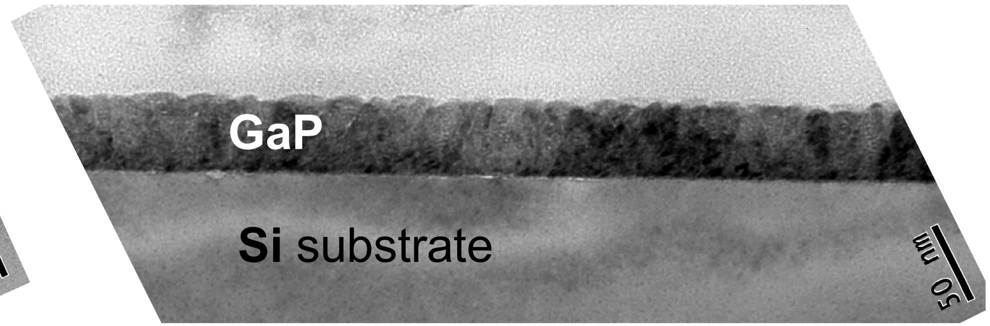
RMS = **3.76** nm



Ar plasma surface activation



RMS =**1.8** nm



First MOCVD growth of GaP on GaP/Si templates

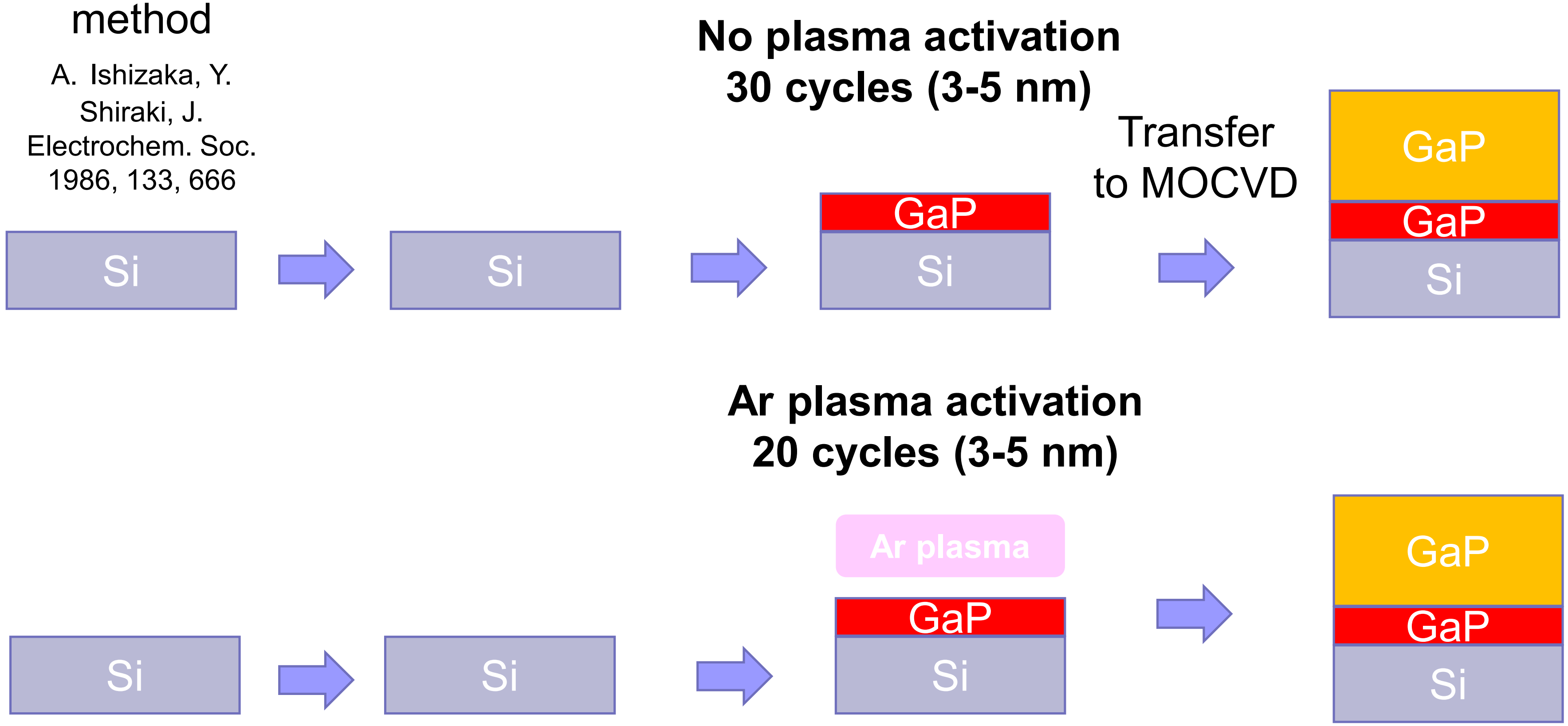
Si substrates cleaning by the *Shiraki* method

A. Ishizaka, Y. Shiraki, J. Electrochem. Soc. 1986, 133, 666

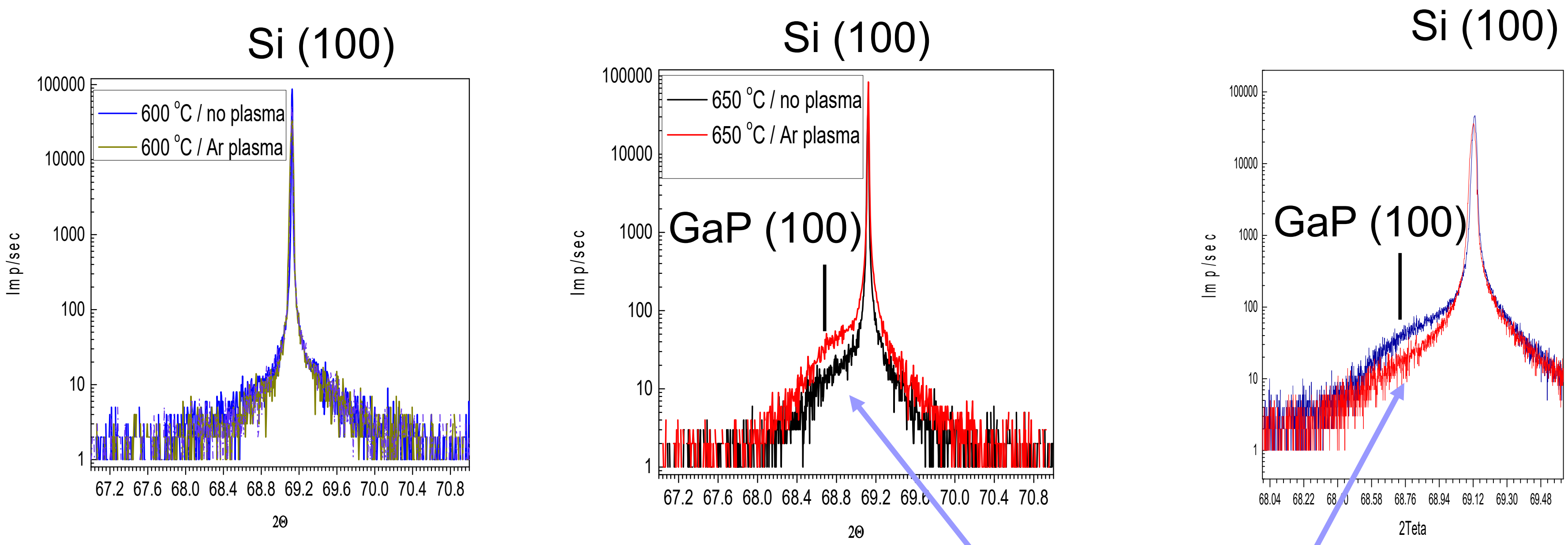
HF dip (oxide removing, H-passivation)

PE-ALD of ultrathin GaP T 380 °C

MOCVD growth of GaP Aixtron AIX 200/4 **T 600 …725 °C**



XRD for GaP grown on GaP/Si templates

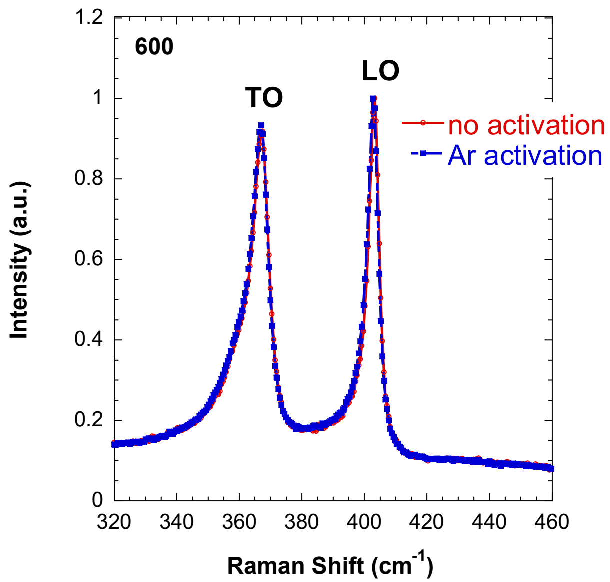


MOCVD growth @ 600 °C   MOCVD growth @ 650 °C   MOCVD growth @ 725 °C

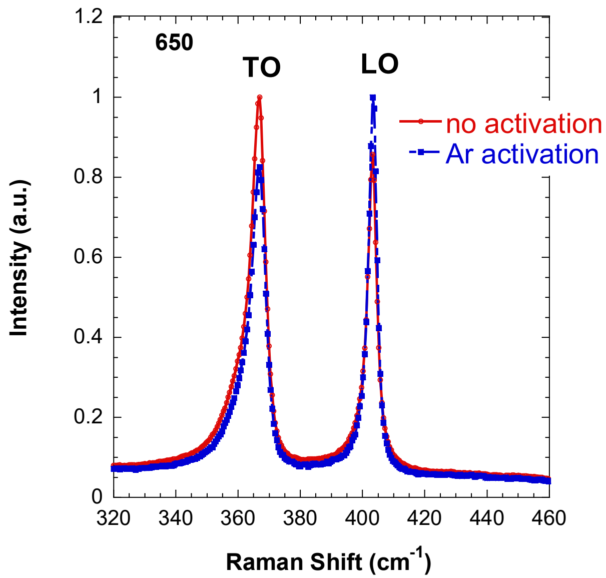
Epitaxial growth was achieved!

Raman spectra of GaP on Si

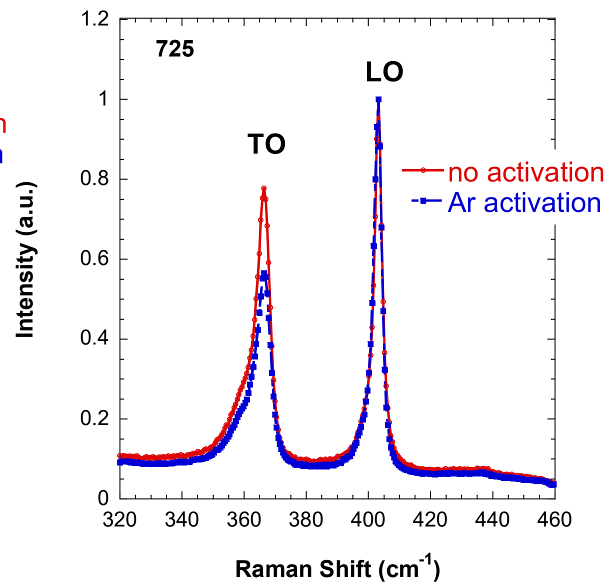
600 °C

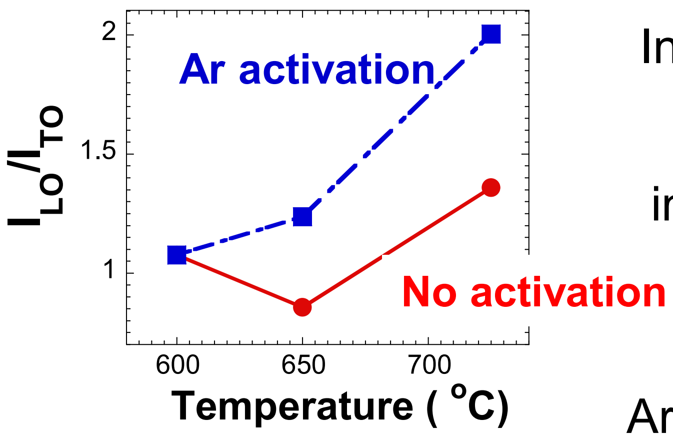


650 °C



725 °C





Increase of LO/TO peak intensity ratio

↓

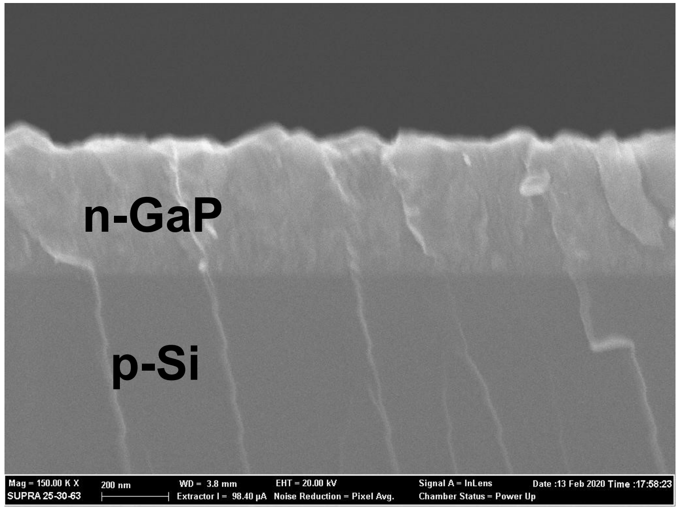
improvement of GaP crystalline quality

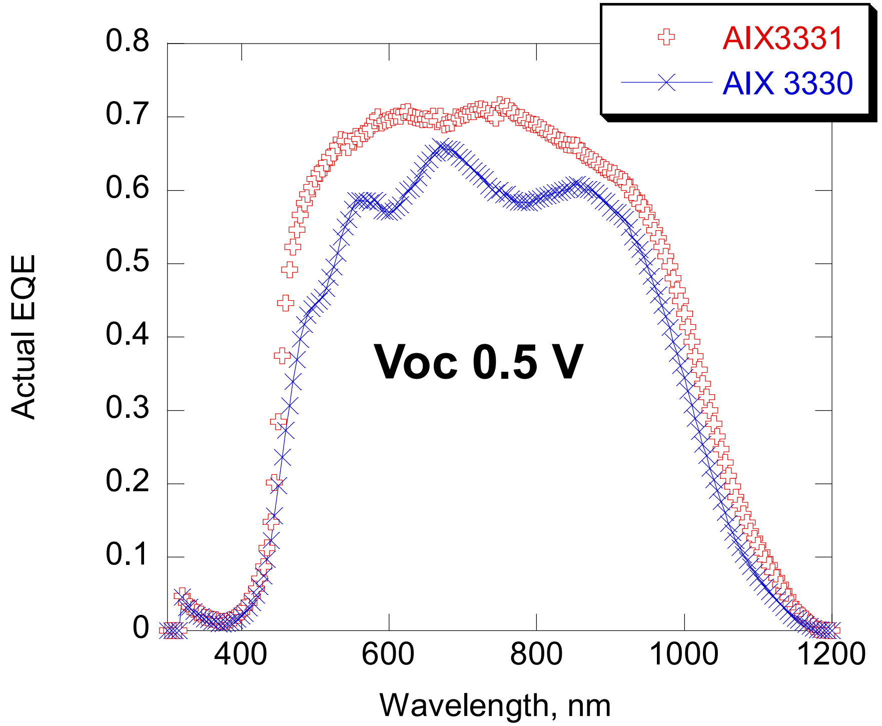
↓

D. Pastor et al J. Appl. Phys. ***106****, 053510 (2009).*

Ar plasma activation provides better structural properties

First n-GaP/p-Si test cell grown by MOCVD on GaP/Si template





epi-GaP/Si interface fabricated by PE-ALD is stable for further MOCVD growth of GaP at the temperature up to 750 °C

Conclusions

- **epi-GaP/Si interface** fabricated by PE-ALD are stable with temperature up to 750 C
- PE-ALD GaP **without H_2 plasma** provides better interface properties
- **Ar plasma surface activation** during PE-ALD could provide better crystalline properties for further GaP growth

Thank you very much for your attention!

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