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X-ray Coherent Scattering on GaP/Si for III-V Monolithic Integration on Silicon

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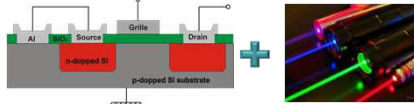
³Univ. Grenoble Alpes, CEA, DRFMC, INAC, Grenoble, France

⁶IPR, UMR 6251, Rennes, France

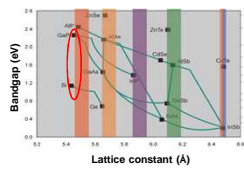
Motivation: Imaging of APB and other crystalline defects in GaP/Si nanolayers in the framework of III-V monolithic integration for photonics and PV on Si

Introduction

Silicon Photonics



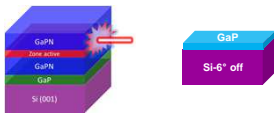
Microelectronic material: Si



GaP/Si: $\Delta a/a = 0.4\%$ at 300K

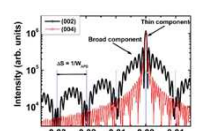
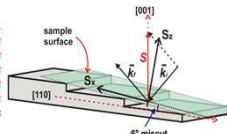
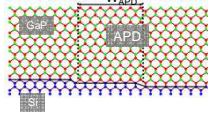
Ref [1]&[2]

GaP as template for III-V/Si monolithic integration

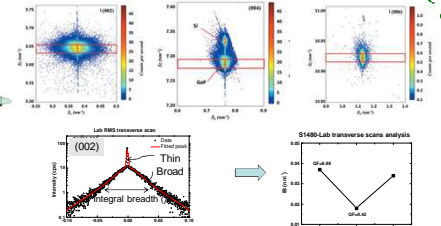


Schematics of a target structure for III-V laser emission on silicon.

photonics and PV on Si

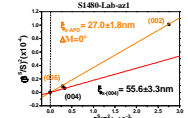


S1: 45nm GaP/Si



$$\left[\frac{\beta(s)}{S} \right]^2 = \frac{1}{\xi_x^2} \frac{\beta(s)}{S^2} + \Delta M^2$$

Correlation length Mosaic term



Macroscopic characterisation of antiphase boundaries

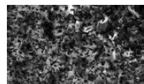
Williamson-Hall like analysis applied to APB (ref [3])

Coherent diffraction

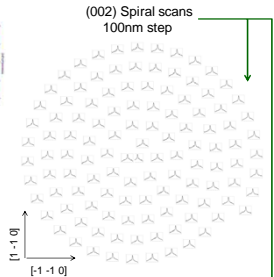
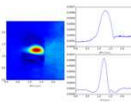
250nm (V) x 500nm (H) coherent beam

S1: 45nm GaP/Si

- Too high APB density / beam size
- Quite uniform XRS
- No Ptychography convergence

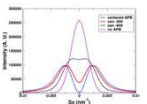


(002) DF-TEM plan view of a similar sample



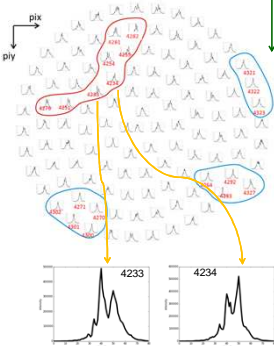
S2: 218nm GaP/Si

- Lower APB density
- Large contrast
- But no ptychography convergence
- Still too high defect density (APB&strain)



Simulation of a single APB lateral scan ~75nm step

- Symmetric peak profile
- Peak splitting extension ~300nm for ~500nm beam width



- Peak splitting (single APB)
- Peak broadening (several APB)

- Asymmetric peak profiles
- Tilt contribution ?

References:

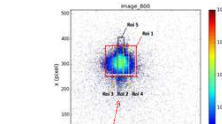
- [1] Y. Takagi, H. Yonezu, K. Samonji, T. Tsuji, N. Ohshima J. Cryst. Growth. **187** (1998) 42-50.
- [2] Volz, K. et al. GaP-nucleation on exact Si (001) substrates for III/V device integration. J. Cryst. Growth **315**, 37 - 47 (2011).
- [3] Y. Ping Wang, A. Létoublon et al., Journal of Applied Crystallography, 2015, 48 (3), pp.702-710.
- [4] M. I. Richard, ACS Appl. Mater. Interfaces **2015**, 7, 26696-26700.
- [5] M. H. Zoellner et al., ACS Appl. Mater. Interfaces **7**, 9031 (2015).
- [6] P. Guillemé et al. accepted in Optics Express.

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Fast XRS scanning kmap technique

100nm (V) x 300nm (H) nano beam



S2: 140nm GaP/Si

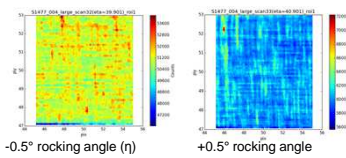
(002) kmap

- Combined Roi 3 & 4 image
- +Tilt regions aligned along [1 -1 0]

- Strain related to APB ?

(004) Kmap

« Weak beam » conditions



Straight lines of contrast parallel to [110] & [1-10] directions

This high tilt contrast, may corresponding to regions surrounding misfit dislocations (see ref [4]&[5])

See ref [4]

Conclusion and projects

First ptychography attempt

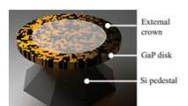
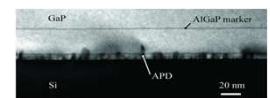
- **Observation of strong contrasts**
 - splitting, broadening, tilt

Fast scan kmap: 2 different contrasts

- **Weak tilt => strain related to APB ?**
- **High tilt => misfit dislocation ?**

Prospects:

- **Reproducible APB annihilation after 10nm**
 - high perfection samples below critical thickness => ptychography imaging
- **Combined analysis of local properties (crystallographic and physical)**
 - Better comprehension of device performances
- **Requires massive 3D Bragg peak analysis (WHL, strain&tilt...)**



GaP/Si microdisk for Second Harmonic Generation [6]