REPORT DOCUMENTATION PAGE	Form Approved OMB NO. 0704-0188

1. REPORT DATE (DD-MM-YYYY) 11-03-2014	2. REPORT TYPE Related Material	3. DATES COVERED (From - To) -

4. TITLE AND SUBTITLE Use of atomic hydrogen to prepare GaSb substrates for subsequent ZnTe growth by MBE	5a. CONTRACT NUMBER W911NF-10-1-0335
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER 611102
6. AUTHORS Thomas H. Myers (presenter)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES Texas State University 601 University Dr. San Marcos, TX 78666 -4684	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES) U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211	10. SPONSOR/MONITOR'S ACRONYM(S) ARO
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) 57432-EL.20

12. DISTRIBUTION AVAILIBILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT

ZnTe is of current interest for photovoltaic applications and as a possible buffer layer for growth of HgCdTe or HgCdSe. Moreover, the ZnTe/GaSb heterostructure itself is of potential interest for cascade solar cells. Thus, different approaches geared towards optimizing the epitaxial growth of high quality ZnTe/GaSb are under active investigation. Atomic hydrogen was investigated for surface preparation of GaSb for subsequent growth of ZnTe and ZnTeSe. A detailed microstructural study of these ZnTe/GaSb samples was performed using cross-section transmission electron microscopy as well as x-ray photoelectron spectroscopy, x-ray diffraction, atomic force

15. SUBJECT TERMS

atomic hydrogen GaSb ZnTe MBE

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Thomas Myers
a. REPORT UU	b. ABSTRACT UU	c. THIS PAGE UU	UU		19b. TELEPHONE NUMBER 512-245-6711

Standard Form 298 (Rev 8/98)
Prescribed by ANSI Std. Z39.18

Report Title

Use of atomic hydrogen to prepare GaSb substrates for subsequent ZnTe growth by MBE

ABSTRACT

ZnTe is of current interest for photovoltaic applications and as a possible buffer layer for growth of HgCdTe or HgCdSe. Moreover, the ZnTe/GaSb heterostructure itself is of potential interest for cascade solar cells. Thus, different approaches geared towards optimizing the epitaxial growth of high quality ZnTe/GaSb are under active investigation. Atomic hydrogen was investigated for surface preparation of GaSb for subsequent growth of ZnTe and ZnTeSe. A detailed microstructural study of these ZnTe/GaSb samples was performed using cross-section transmission electron microscopy as well as x-ray photoelectron spectroscopy, x-ray diffraction, atomic force microscopy and imaging photoluminescence measurements. We will present results indicating that we are able to get smooth, clean and stoichiometric GaSb surfaces suitable for subsequent epitaxial growth without using an Sb overpressure. In particular, ZnTe layers with thicknesses of 200 nm and below have highly coherent and sharp interfaces with the GaSb, and exhibit very low densities of dislocations. Thick ZnTeSe/GaSb layers with dislocation densities in the mid-104 cm-2 have been grown.

buffer layer for growth of HgCdTe or HgCdSe. Moreover, the ZnTe/GaSb heterostructure itself is of potential interest for cascade solar cells. Thus, different approaches geared towards optimizing the epitaxial growth of high quality ZnTe/GaSb are under active investigation. Atomic hydrogen was investigated for surface preparation of GaSb for subsequent growth of ZnTe and ZnTeSe. A detailed microstructural study of these ZnTe/GaSb samples was performed using cross-section transmission electron microscopy as well as x-ray photoelectron spectroscopy, x-ray diffraction, atomic force microscopy and imaging photoluminescence measurements. We will present results indicating that we are able to get smooth, clean and stoichiometric GaSb surfaces suitable for subsequent epitaxial growth without using an Sb overpressure. In particular, ZnTe layers with thicknesses of 200 nm and below have highly coherent and sharp interfaces with the GaSb, and exhibit very low densities of dislocations. Thick ZnTeSe/GaSb layers with dislocation densities in the mid-10^4 cm^{-2} have been grown.

Growth Details

50 - 2100 nm ZnTe
GaSb(100) or GaSb(211)

ZnTe/GaSb study

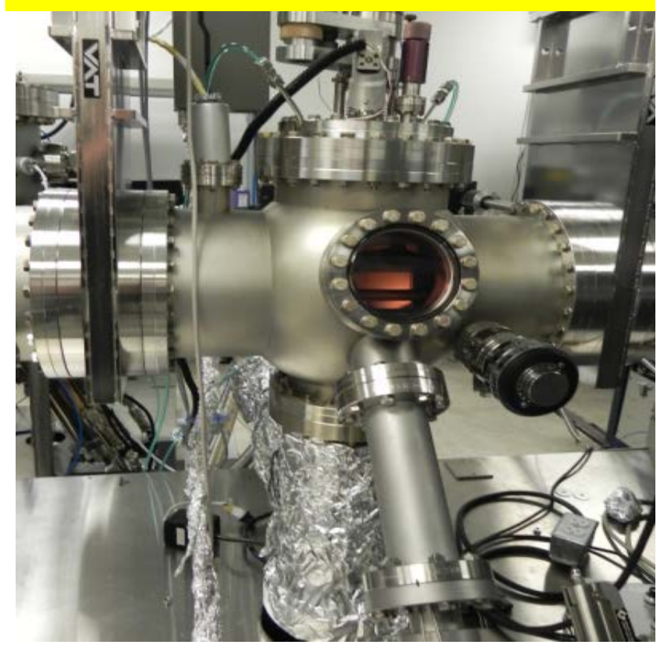
1 – 2 µm ZnTeSe
~ 150 nm ZnTe
GaSb(100) or GaSb(211)

ZnTeSe/GaSb study

- **Grown with Elemental Zn and Te.**
- **Oxides removed by 20 min exposure at 400°C to atomic**
- **During nucleation, the substrate temperature was raised to 320°C and the surface was exposed to Zn for 60s**
- **This was followed by ten periods of alternating exposures of Zn and Te for 5s and Zn for 60s.**
- **ZnTe layers between 50 to 2100 nm thick were deposited.**

Oxide Removal Methods

H_2 Cleaning



1. Thermal Oxide Desorption

$$2Sb_2O_5 \rightarrow Sb_4\uparrow + 5O_2$$

$$Ga_2O_3 \rightarrow Ga_2O + O_2$$

Decomposes > 550 °C

$$4GaSb + 3O_2 \rightarrow 2Ga_2O_3 + Sb_4\uparrow$$

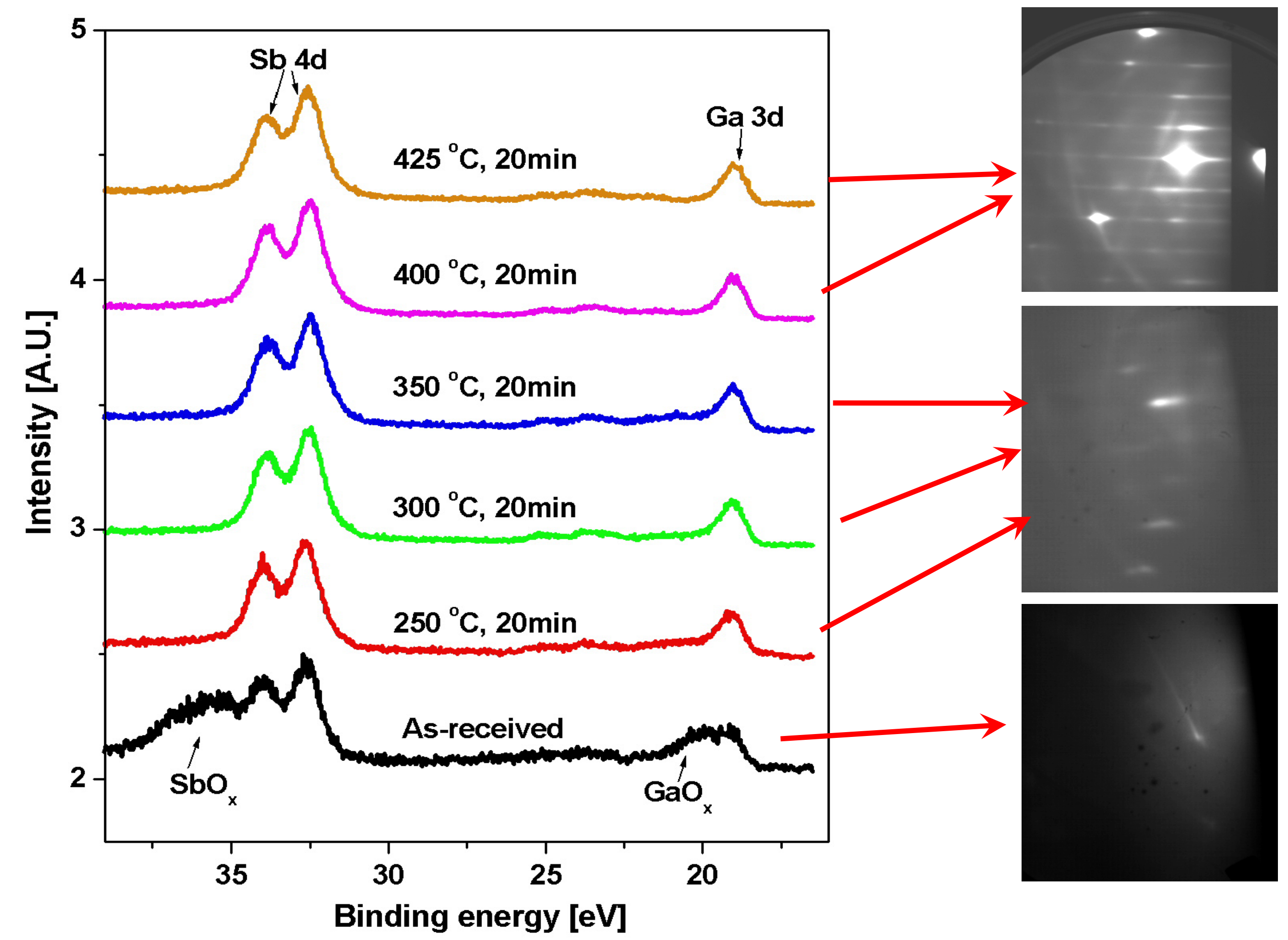
2. Atomic Hydrogen Cleaning

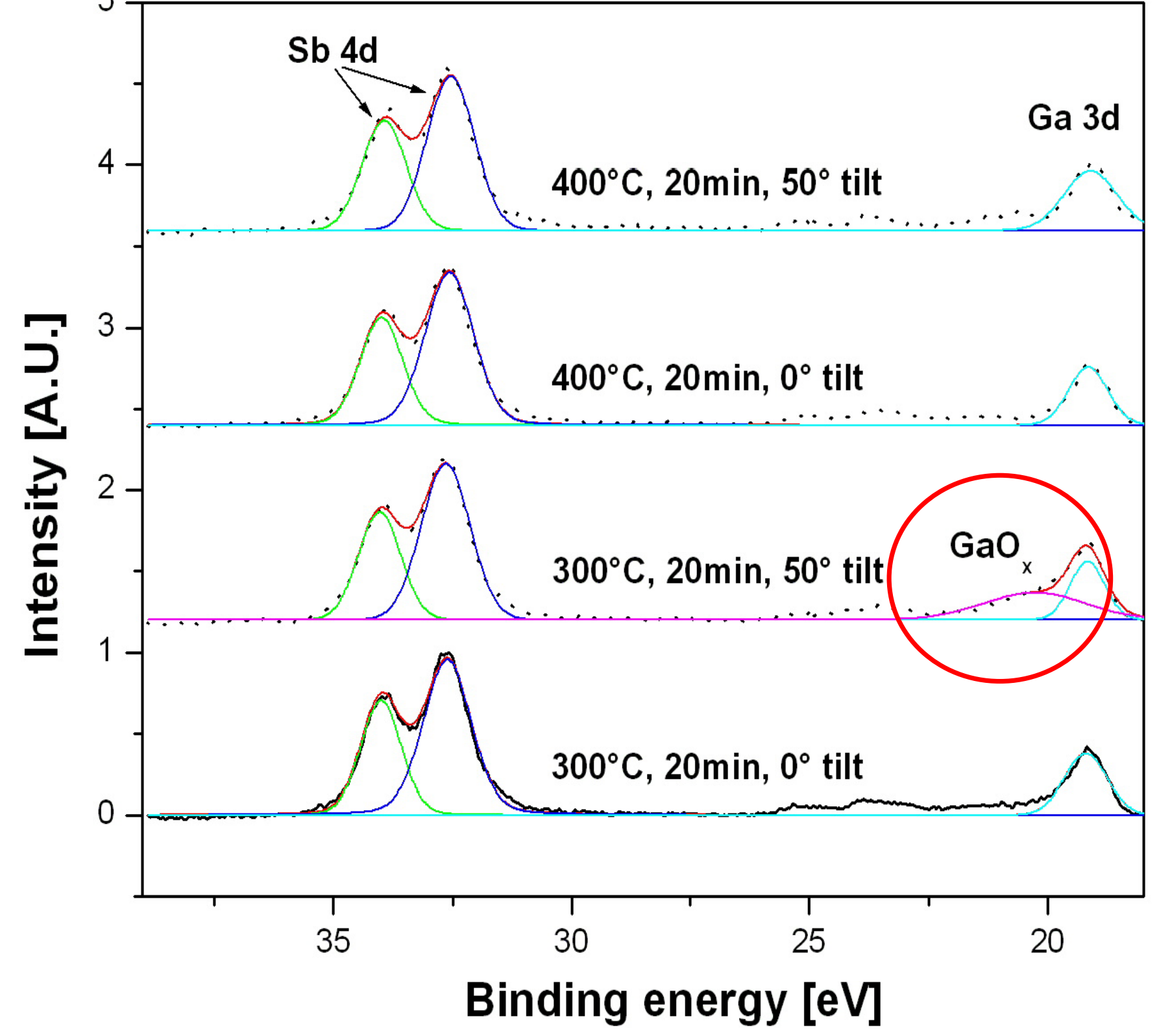
Desorbs > 400 °C

$$Ga_2O_3 + 4H \rightarrow Ga_2O + 2H_2O\uparrow$$

$$2Sb_2O_5 + 20H_2 \rightarrow Sb_4 + 10H_2O$$

Ref 1. *J. Vac. Sci. Technol*. A 25(4), Jul/Aug 2007



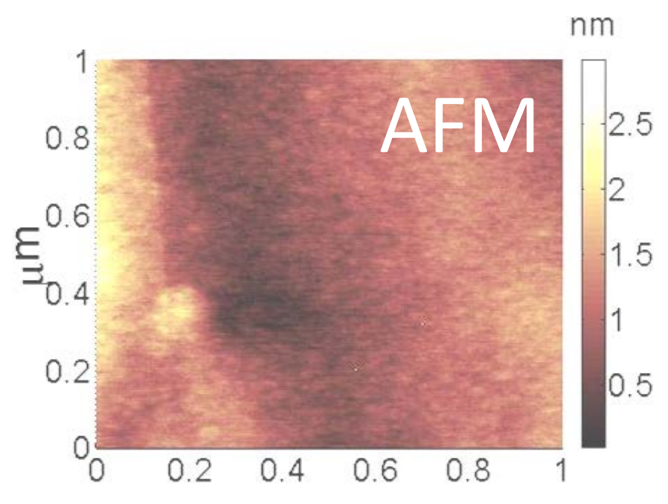


XPS and RHEED indicate atomic-H cleaning at 400°C is required to remove surface oxides

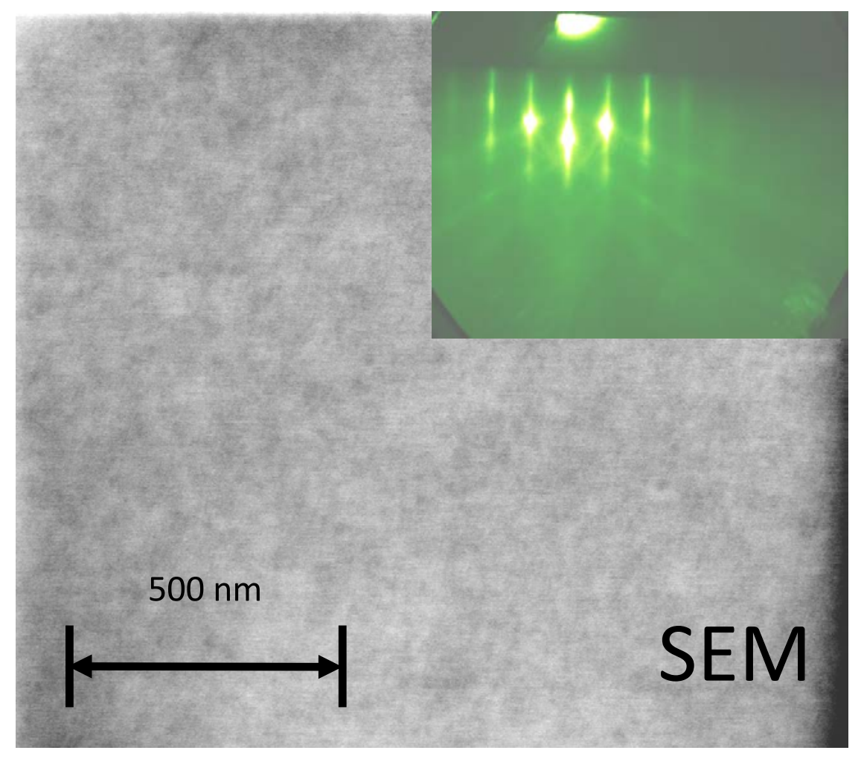
XPS : Composition Analysis on Atomic-H Cleaned GaSb

#	Orientation	Method	Temperature (°C)	Normalized Ga/Sb
(1)	(100)	Thermal, Sb Overpressured	560	0.72
(2)	(100)	MBE GaSb films	560	1.00
(3)	(211)B	Thermal only	400	4.79
(4)	(211)B	aH only at T*, 30min	400	0.97
(5)	(211)B	aH only at T, 60min	400	1.35
(6)	(211)B	aH only at T, 30min	400	1.43
(7)	(211)B	aH from RT T**, 30min	400	1.02
(8)	(211)B	aH from RT T, 60min	400	1.03

*aH only at T : Heating first and H_2 cleaning
**aH from RT : H_2 cleaning at RT first and heating



RMS
~0.153 nm



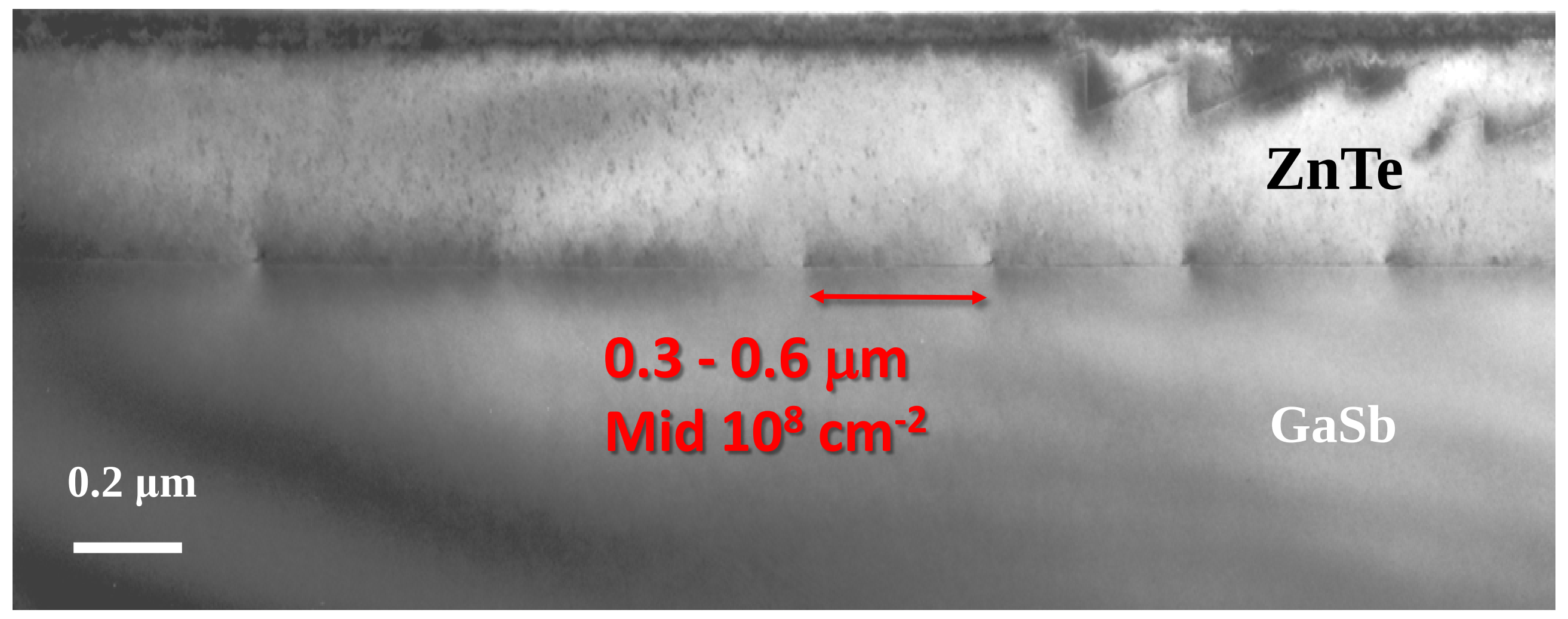
Use Large Atomic-H Overpressure

$$\cancel{4GaSb + 3O_2 \rightarrow 2Ga_2O_3 + Sb_4}$$

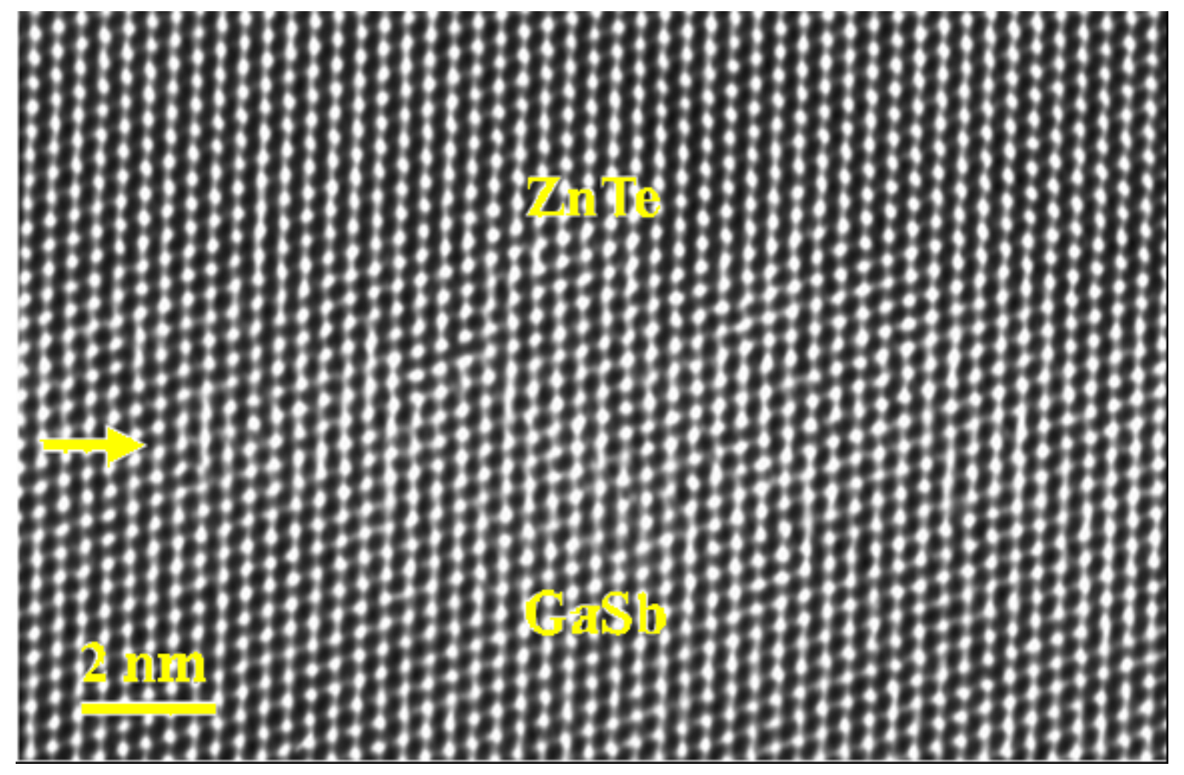
$$Ga_2O_3 + 4H \rightarrow Ga_2O + 2H_2O$$

$$2Sb_2O_5 + 20H_2 \rightarrow Sb_4 + 10H_2O$$

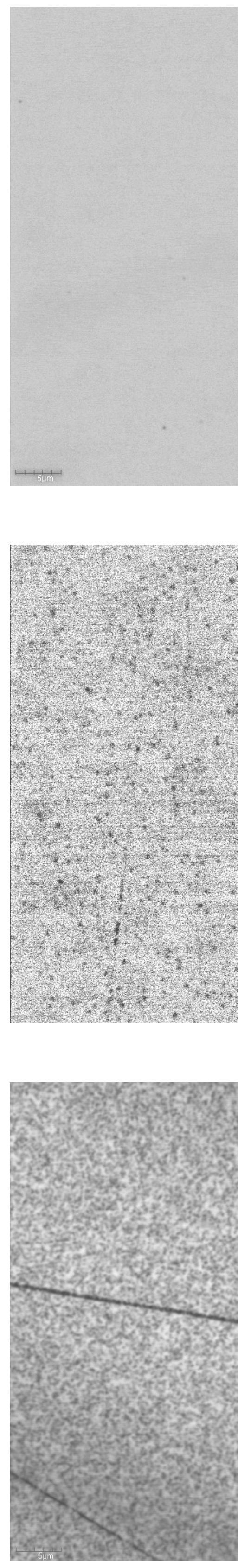
Top surface

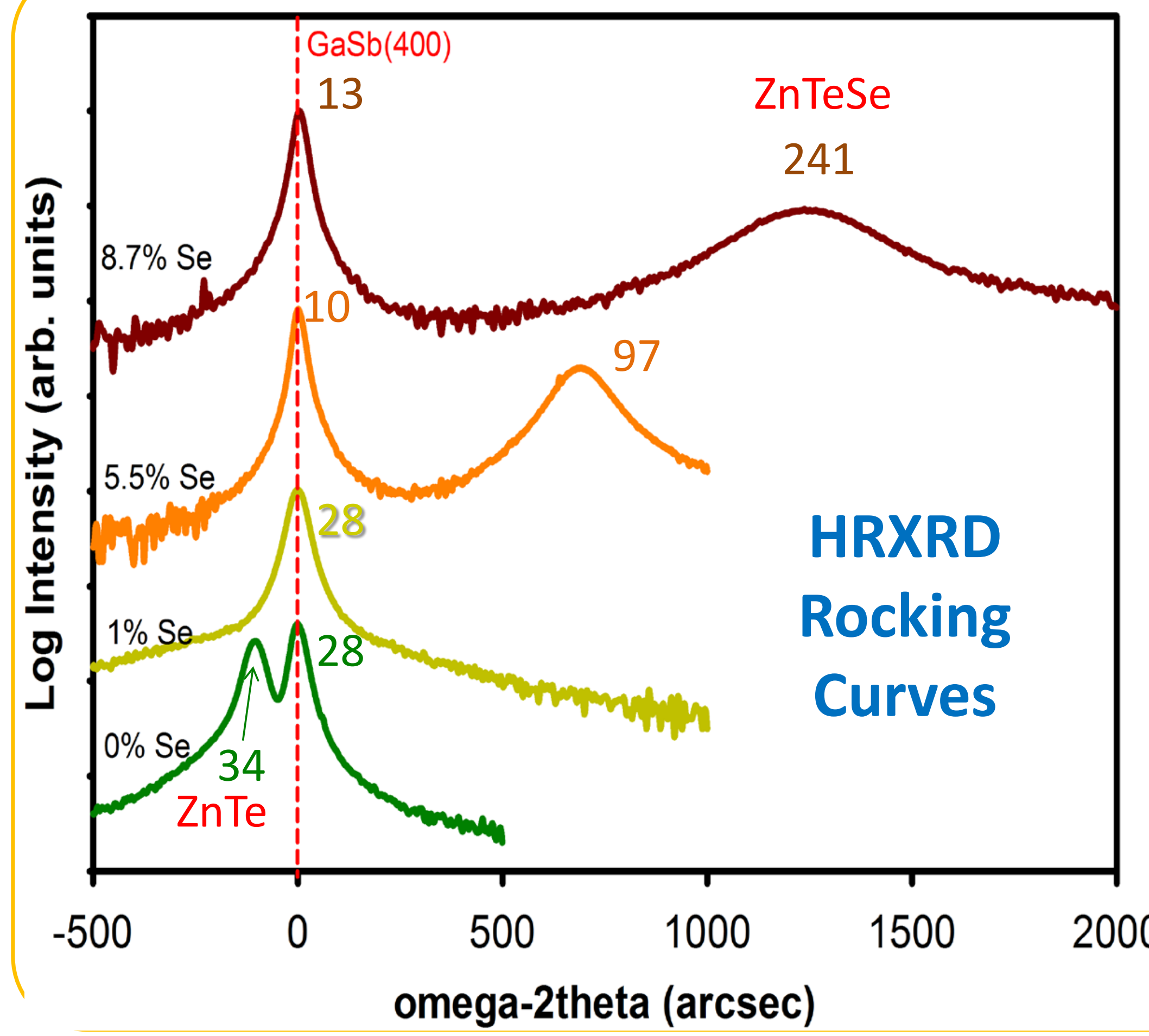


TEM

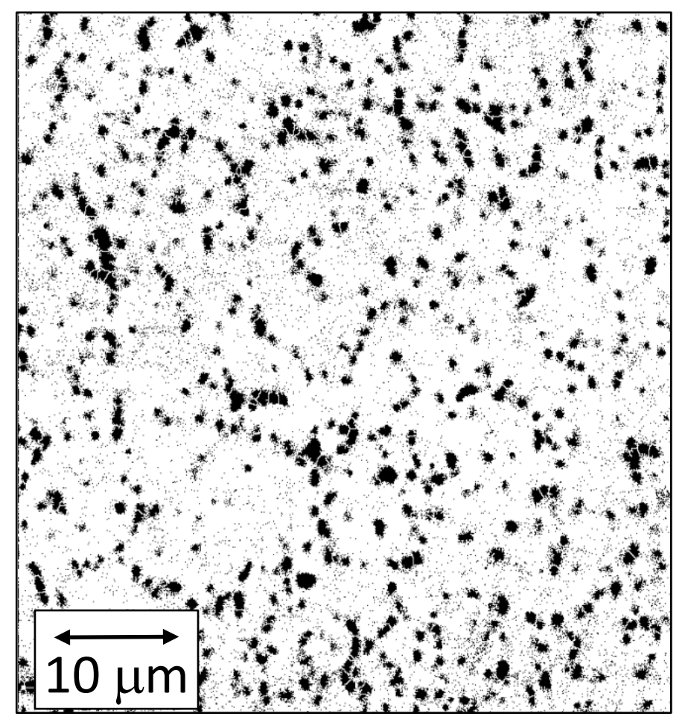


Confo

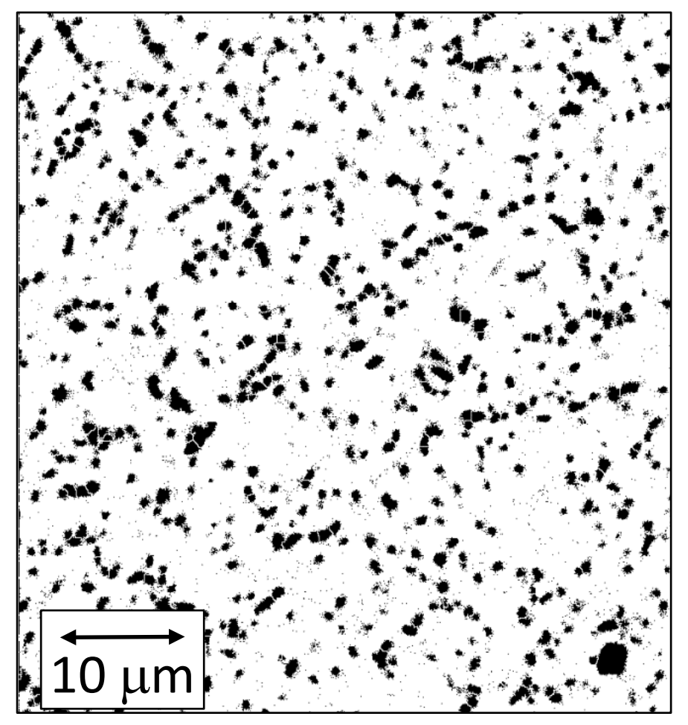




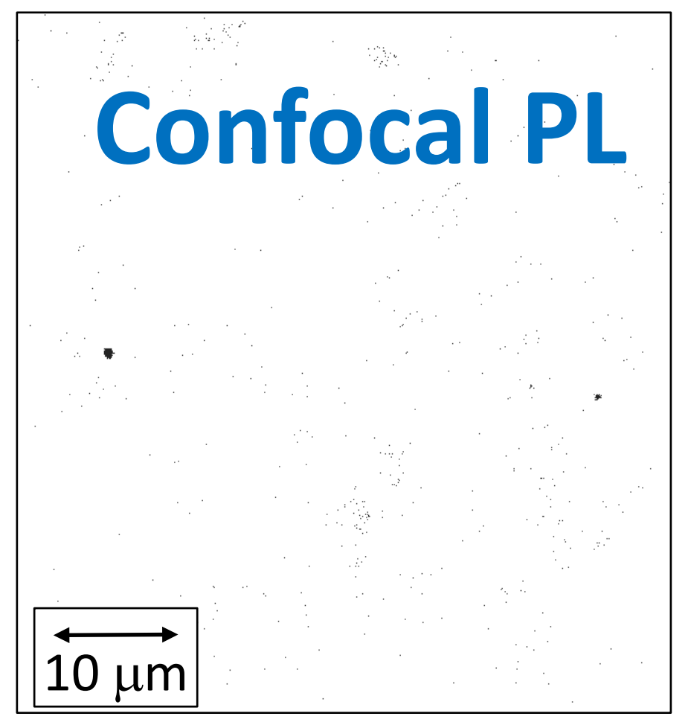
Lattice Matching and Atomic-H Cleaning Results in Low Dislocation Epilayers



~3x10^7 cm^{-2}
2-µm thick
ZnTe/GaSb (211)B



~3x10^7 cm^{-2}
2-µm thick
ZnTe/GaSb (100)



~7x10^4 cm^{-2}
1.2-µm thick
ZnTe$_{0.99}$Se$_{0.01}$/GaSb (211)B