UNDERSTANDING INTERPHASE FORMATION IN NANO-BONDING™ OF GAAS TO SI IN AIR AT T ≤ 220°C VIA SURFACE ENERGY ENGINEERING (SEE) BASED ON 3LCAA, IBA, XPS, SAM AND TEM.

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APPROACH

Recently, three techniques are combined to measure (a) Surface Energy γ^T/ hydro-affinity by 3LCAA (Fig.1) (b) absolute composition by High Resolution IBA (HR-IBA) (Fig.2) and (3) bonding by XPS , before and after Surface Energy Engineering (SEE) on several wafers. ***Measuring first the modification of γ^T and hydro-affinity before DWB via Nano-Bonding™ enables the rapid optimization of SEE in few steps.***

Next, Nano-Bonding™ is conducted on the engineered surface pairs in a Class 100/ISO 5 clean-room at T <220°C using nano-contacting, mechanical compression ranging from 5 to 15 psi (~ 35 - 100 kPa) and about 1-3 psi (~ 7- 20 kPa) of steam pressurization over the stacked wafer pair..

After NanoBonding™, debonding tests using 1-20 psi (7- 150 kPa) of pressure to separate the wafers, Surface Surface Acoustic wave Microscopy (SAM) and High Resolution Cross-section Microscopy are used to quantify the bond strength achieved via Nano-Bonding™ , the surface area bonded and characterize the bonding interphase.

RESULTS

An example of Surface Acoustic wave Microscopy (SAM) in Fig.1 shows that effective NanoBonding™ of up 98% of the mechanically compressed area can be achieved in atmosphere instead of UHV using steam pressurization of 2-3 psi, T ≤ 220°C, and 60 kPa of mechanical compression.

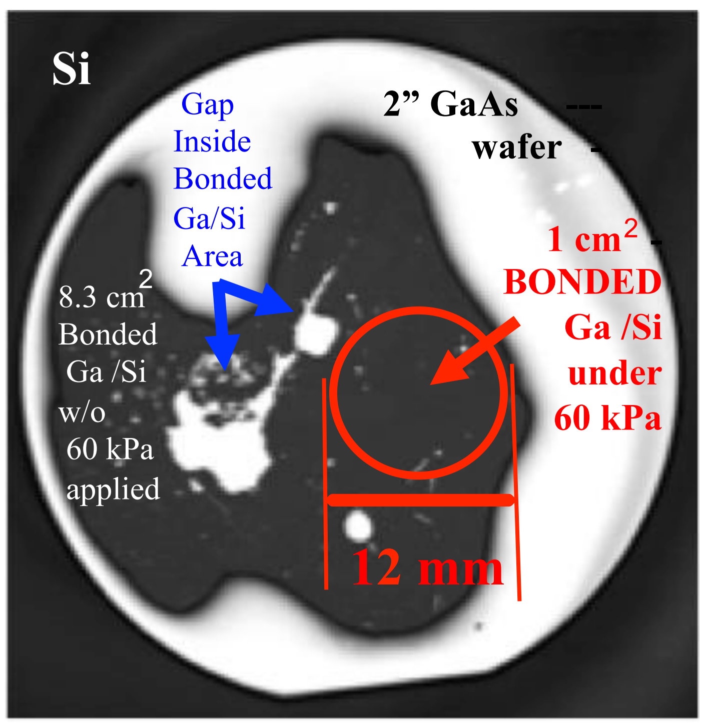


Fig. 1. *Surface Acoustic Wave Microscopy (SAM) imaging of a 50 mm +Te-doped GaAs (100) wafer bonded to a 100 mm p- B-doped Si (100).*

The bonded GaA-Si area is circled in red and matches the 60 kP mechanically compressed area.

The 50 mm white disk delineates the contour of the 2” GaAs wafer on top while the 4” Si wafer appears in black underneath.

The GaAs/Si bonded interface appears in black inside the white GaAs wafer contour. Outer, non-bonded regions appear in very light grey because water has seeped between GaAs and Si wafers.

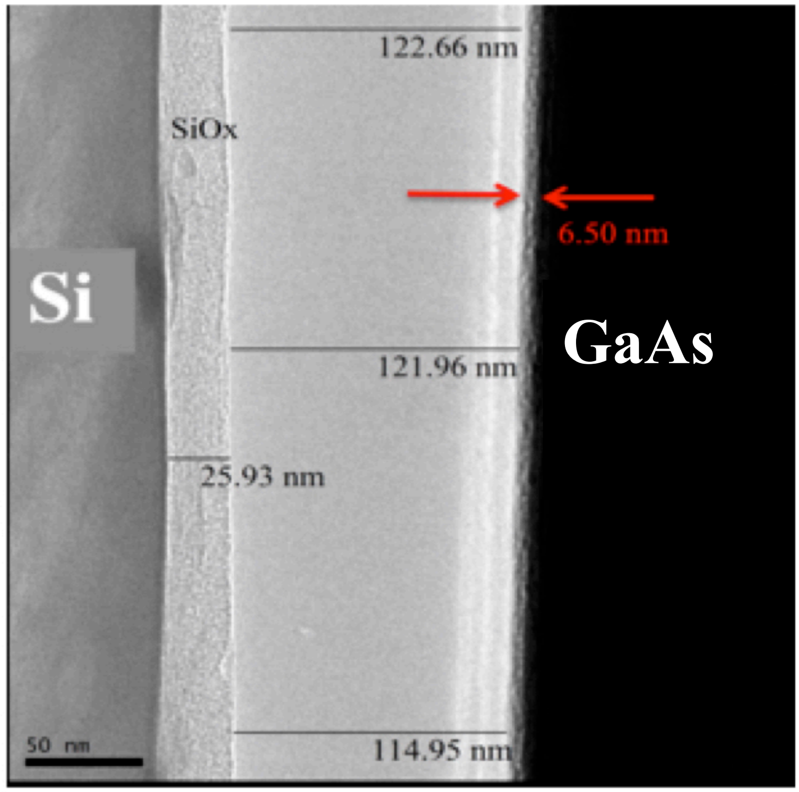
Inside the bonded interfacial regions, stark white small area’s are local area inside the bonded region where defects, particulate or local warp has inhibited contacting and bonding.

Conclusions from SAM analysis

1. As shown in Fig. 1 by Surface Acoustic Microscopy, 98±1 % of the cm^2 GaAs area that was nano-contacted and mechanically compressed to Si with 60 kPa of uniform pressure has sucessfully nano-bonded after 1psi steam pressurization and anneal at T < 220°C. The 1 cm^2 surface area in the compressed nano-contacted region circled in red in Fig.1.
2. In addition, 48±1% of the whole 19.6 1 cm^2 GaAs wafer surface area also bonded to Si, beyond the surface area being mechanically compressed due to the reactivity of the 2D precursor phases.
3. SAM also reveals that discontinuities in the interfacial bonding where contacts is not achieved in three macroscopic areas, of several mm in diameter, Several small defects are seen and appear related to particulate contamination, indicating that Class 100/ISO 5 is not sufficient and that Class 10/ISO 4 particulate control is required.

Conclusions from Cross-Sectional Analysis by TEM (TEM)

Fig. 2: *Cross-section TEM of an air gap detected by SAM in a nano-bonded GaAs(100)/ Si(100) pair.*



TEM cross-section in Fig. 2 reveals do not bond because of significant spatial gaps of the order of 120 nm from macro-scale warping.

TEM also reveals very significant oxidation takes place at T <220°C not the on Si and GaAs with oxides thickness reaching more than 25 nm nm on Si and 6.5 nm on GaAs.

TEM shows how reactive both GaAs and Si surface are after SEE and how modifying γ^T via precursor phases can shift surfaces far-from- equilibrium, modify kinetics and catalyze both cross-bonding and surface oxidation when activated at T <220°C

Constructing a model for the bonding interphase GaAs (100) to Si(100)

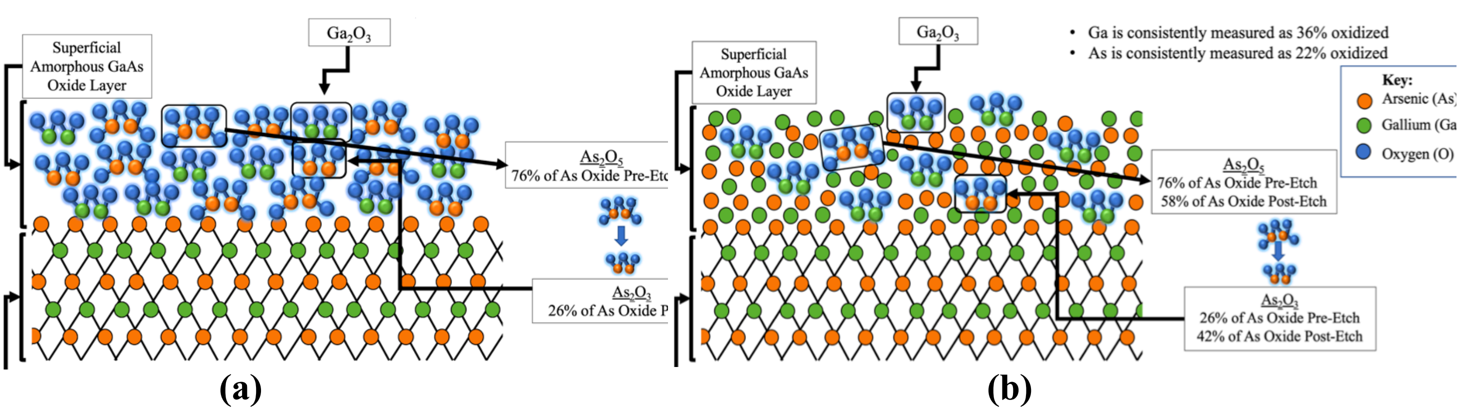


Fig.3 *Proposed Ball and Stick Model for Surface Oxidse GaAs(100) in air before SEE (a) and after SEE (b) before Nano-Bonding™*