Surface crystallography improvements induced by evaporated Ti film on selected semiconductors – LEED and AES measurements

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Introduction

Further improvements of electronic devices towards higher performance, efficiency, and power usage depend strongly on the intrinsic properties of the materials used for their fabrication. These desired electrical, magnetic, and optical properties are strongly impacted by material crystallography. In this poster, the components of surface crystallography play an important role as a foundation for the interface formation which is responsible for the function and performance of the specific device. The list of these devices include wide-band semiconductors such as GaN, AlN, SiC and Ga2O3.

This study aims to present ultra-thin Ti films as a structural repair solution for selected semiconducting materials.

Experiment Data

Over the course of characterization and testing with differing materials, the common result of crystallography improvement following Ti deposition was observed in select semiconductors. Crystals which experienced this improvement are:

- ❖ AlN on Si (100)
- ❖ Al2O3 (0001)
- ❖ Ga2O3 (010)
- ❖ PbWO4
- ❖ LiNbO3

Despite differing surface preparation, deposition thicknesses, and treatment after deposition, all materials have been shown to improve after interactions with titanium. The presence of Ti is confirmed using AES and crystallography quality is established with LEED.

Additionally, Si(111) and Ge(111) presented unique results of unchanged reconstruction even after comparatively large Ti depositions.

Process

The sample surface is prepared using high-temperature annealing and often ion bombardment. Surface preparation is completed until the surface crystallography is repaired, resulting in a bright, sharp, and high quality LEED pattern.

Sample	Surface Preparation	Treatment After Ti Deposition
AlN on Si (100)	Annealed to 800˚C	15.9nm total deposition Annealed at 550˚C for 5 minutes
Al2O3 (0001)	Annealed at 693˚C for 5 minutes	10Å deposition Annealed at 693˚C for 5 minutes
Ga2O3 (010)	Ion bombardment for 30 minutes and annealed at 590˚C for 5 minutes	50Å total deposition Annealed at 275˚C for 5 minutes
PbWO4	Annealed at 693˚C for 1 minute	7Å total deposition Annealed at 693˚C for 1 minute
LiNbO3	Annealed at 875˚C for 1 minute	60Å deposition Annealed at 875˚C for 1 minute
Si (111)	Annealed at 925˚C for 1 minute	Annealed at 566˚C for 2 minutes between depositions
Ge (111)	Annealed at 700˚C for 5 minutes	Annealed at 566˚C for 5 minutes between depositions

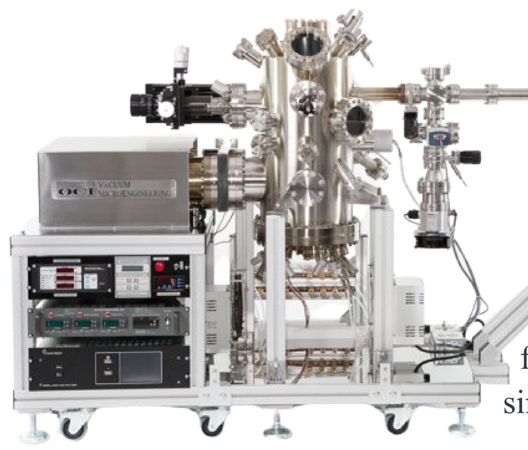
Experimental Setup

Testing was completed in OCI's Molecular Beam Epitaxy (MBE) system (Model IMBE300). Capabilities include:

- ❖ Ti evaporation source (monitored with an incorporated quartz crystal micro-balance)
- ❖ High-temperature annealing (up to 1000ºC)
- ❖ Ion bombardment (Ion Gun Model IG70)

Characterization was completed in the same system with:

- ❖ Low Energy Electron Diffraction (LEED)
- ❖ Auger Electron Spectroscopy (AES) Model BDL800IR



The system is maintained at a vacuum level of ~7e-10Torr or better. In-vacuum sample storage allowed for multiple samples to be tested simultaneously.

Completed Testing

Material

	AlN on Si(100) 110eV	Al2O3(0001) 175eV	Ga2O3(010) 40eV	PbWO4 120eV	LiNbO3 65eV

LEED prior to deposition

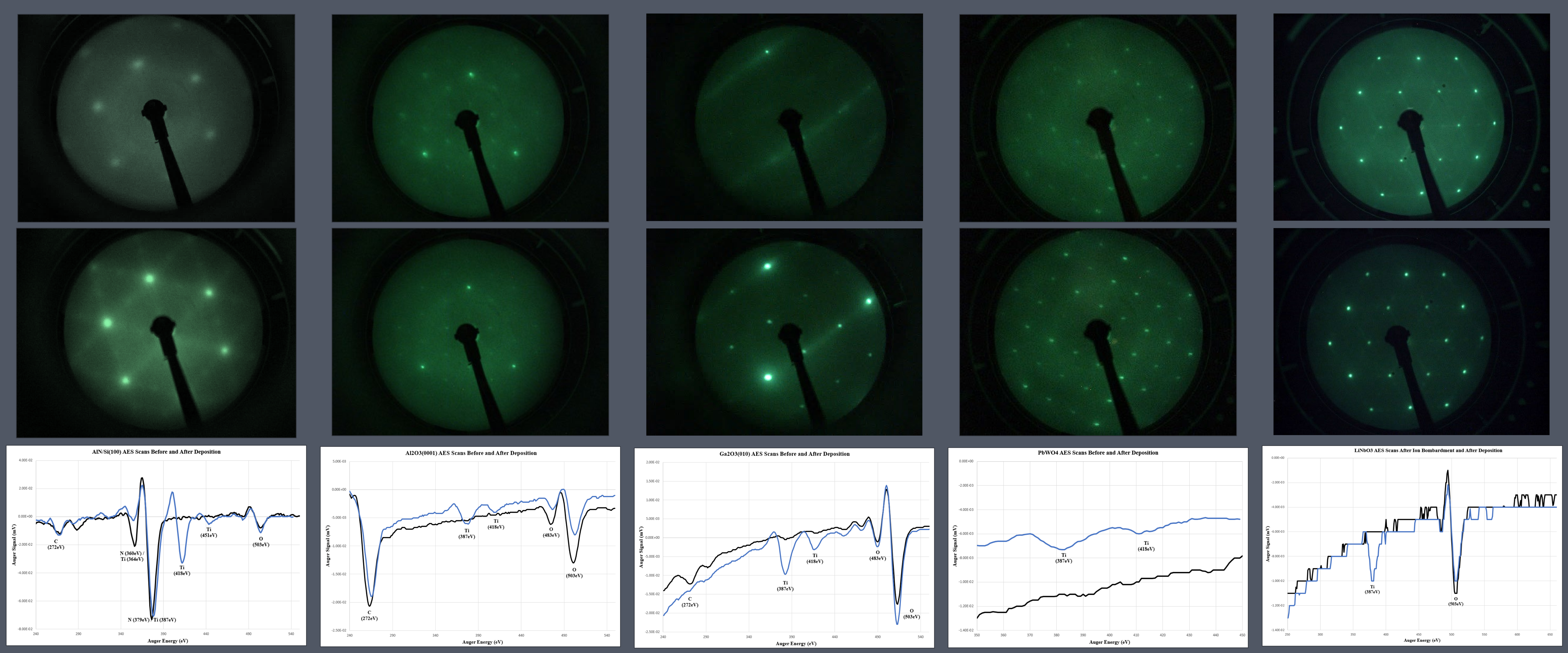
LEED following Ti deposition and annealing

AES spectrum before and after

AES Scan Legend

Before Titanium Deposition

After Titanium Deposition

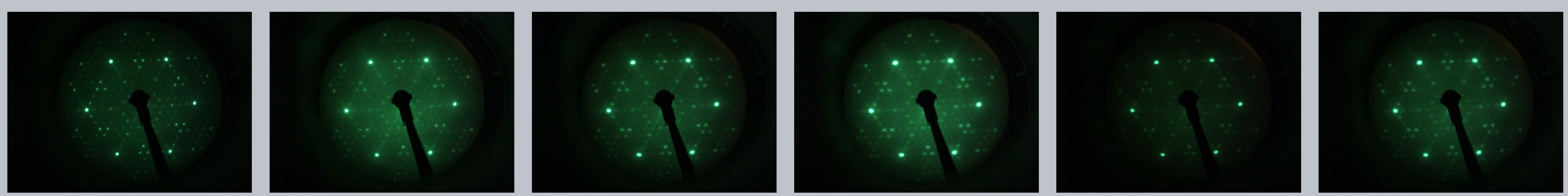


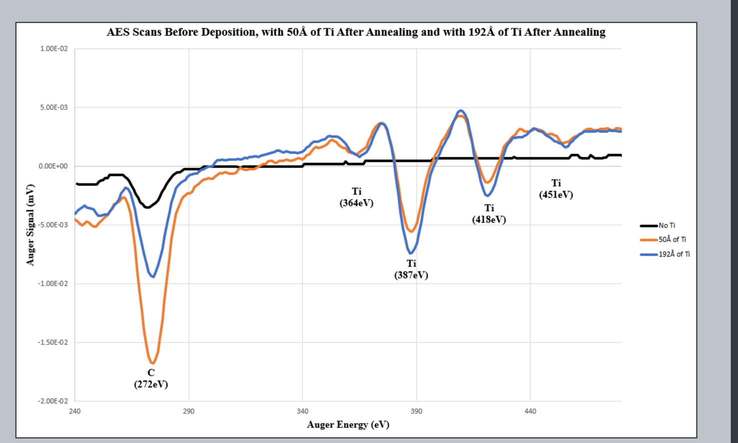
*Note: PbWO4 scan taken immediately after deposition

Titanium ultra-thin film is improving the surface crystallography of selected semiconductors

Titanium on Silicon (111) – 7x7 Reconstruction Remains Unchanged
Each deposition followed by annealing at 566˚C for 2 minutes (50eV)

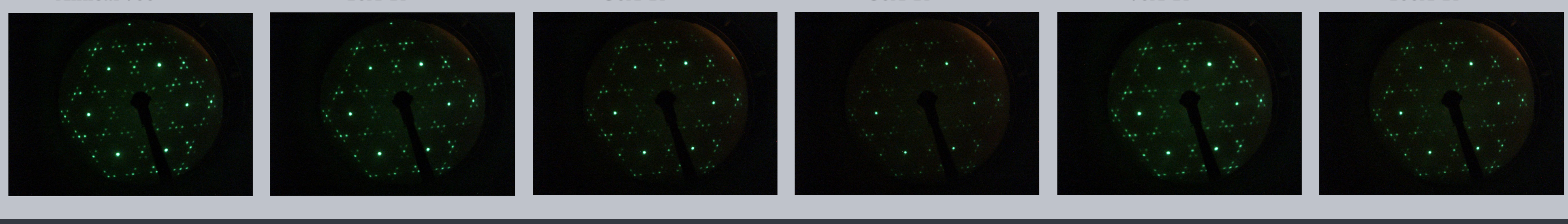
Anneal 925	50Å Ti	100Å Ti	132Å Ti	172Å Ti	192Å Ti

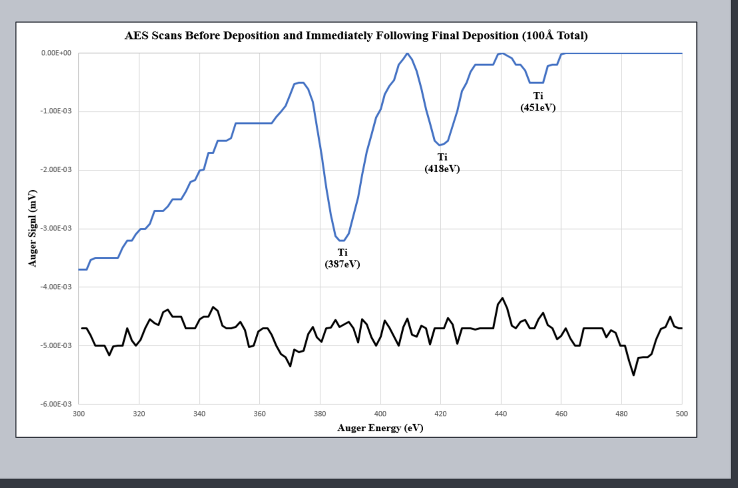




Titanium on Germanium (111) – c2x8 Reconstruction Remains Unchanged
Each deposition followed by annealing at 566˚C for 5 minutes (55eV)

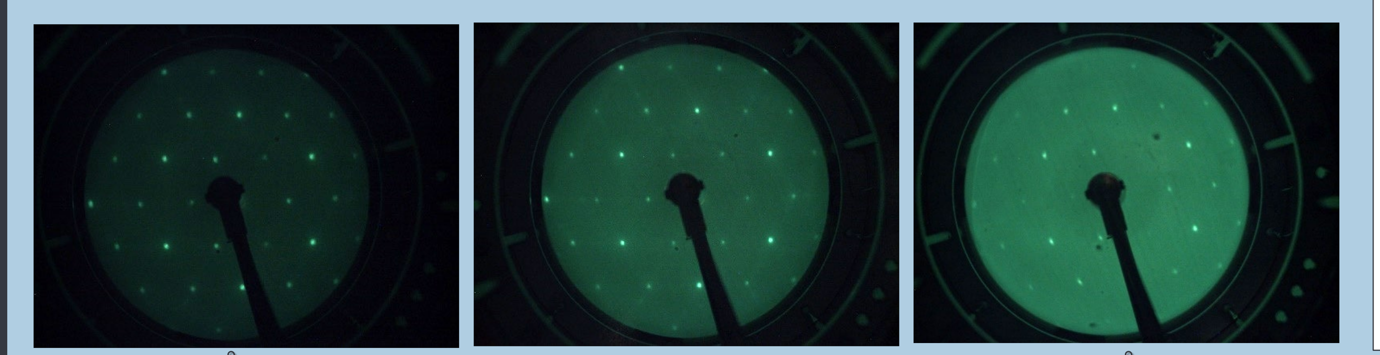
Anneal 700	10Å Ti	30Å Ti	50Å Ti	70Å Ti	100Å Ti



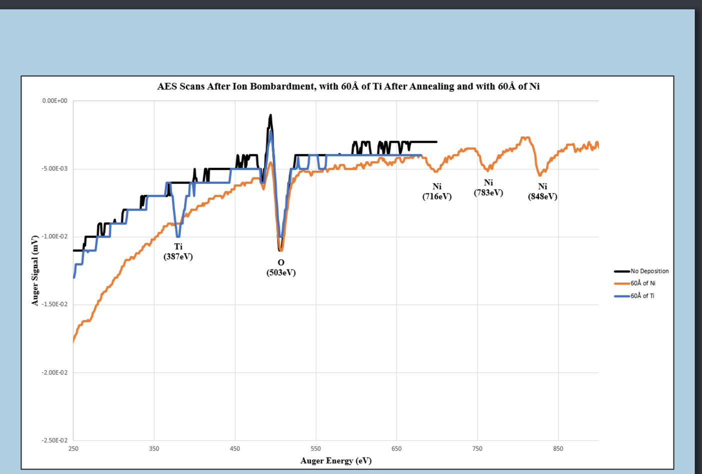


Unexpected **reconstructed epitaxy** of **titanium** on **Si(111)** and **Ge(111)**

Demonstration of Titanium Novelty: Nickel Comparison on Lithium Niobate
Each trial annealed at 875˚C for 1 minute (95eV)



60Å Ti | **No film** | **60Å Ni**



Remarks and Conclusions

A number of conclusions and potential explanations can be formed from the above results:

- ❖ Titanium appears to perform as a "patching" with sub-monolayer film, filling surface defects of many semiconductors and improving the resulting LEED pattern
- ❖ Titanium is the only evaporated metal for which silicon and germanium are observed to retain surface reconstruction
  - ❖ In this case, it appears that the titanium is able to interact in a way which preserves the reconstructed lattice structure

Regardless of the mechanism of improvement, these tests have demonstrated the potential impact that Ti can have on semiconducting substrates. In future device development, an application of an ultra-thin layer of Ti may enhance performance and should be further pursued.

Implications

Semiconductor devices are often grown epitaxially, with a substrate material and film material. Often this growth process can propagate pre-existing unintentional defects and create new ones. To avoid this, we propose some semiconductors could benefit from ultra-thin layers of titanium to prevent the defects formed from poor substrate quality and lattice strain.

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