Epitaxial growth of Weyl semimetal TaAs for energy efficiency and renewable energy applications

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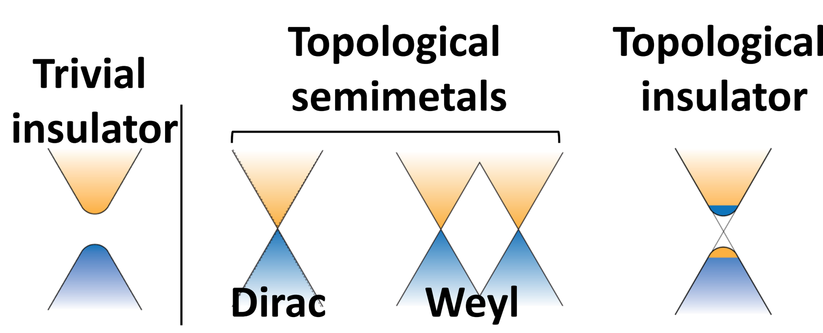
Introduction

- Three-dimensional topological semimetals (TSMs) are recently discovered materials which host extraordinarily high metrics for material quality.
  - Mobilities up to 5×10^6 $cm^2V^{-1}s^{-1}$ (NbP) [1]
  - Extremely high magnetoresistances – 2×10^8 % (WP_2) [2]
  - Resistivity lower than Cu of similar purity (MoP) [3]
- Topological protection prevents backscattering → robust against defects.
- Chiral anomaly – Electric and magnetic fields can create a nearly dissipationless electron current
- Microelectronics projected to reach 20% of worldwide energy use [4]
- Unique properties of TSMs will enable novel applications in energy saving low powered electronics, catalysis and quantum information.
- **Problem: Many TSMs only available as bulk single crystals not suitable for device fabrication**
- **Goal: Close the gap between basic physics research and applications by synthesizing topological semimetals on substrates compatible with semiconductor manufacturing.**

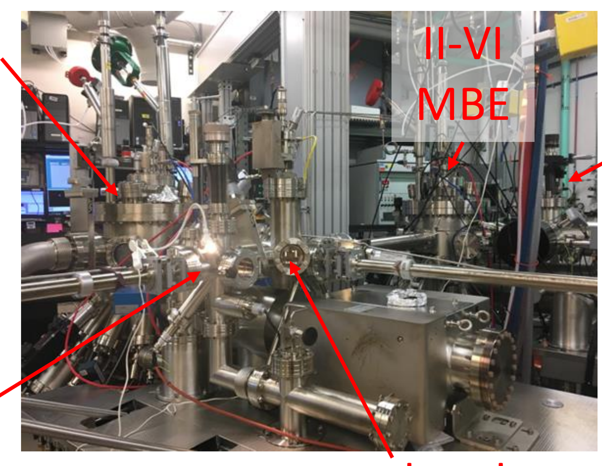


Inversion of conduction and valence bands leads to topological protection

Materials And Methods

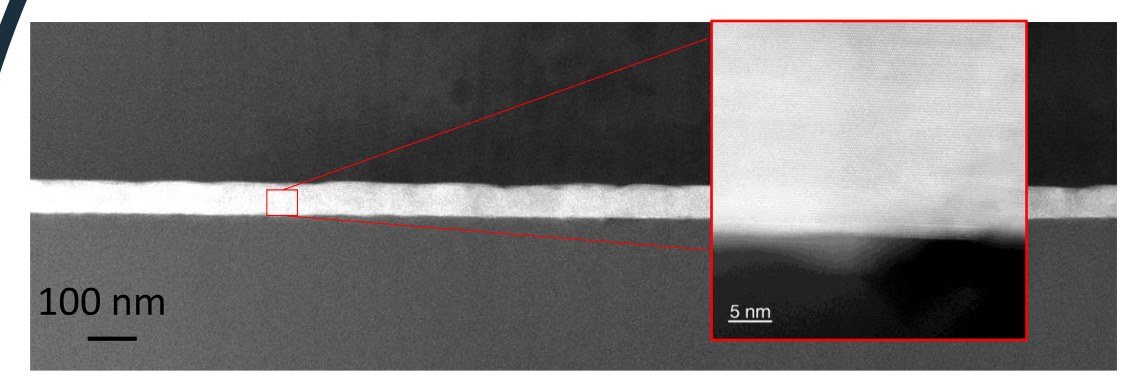
- Molecular beam epitaxy (MBE) used to synthesize high quality epitaxial thin films
- Materials chosen to be compatible with III-V/II-VI semiconductor growth → integrate TSMs into semiconductor manufacturing
- TaAs – first discovered Weyl semimetal in 2015
- Ultrahigh mobility (1.8×10^5 $cm^2V^{-1}s^{-1}$ at 10 K) and giant linear magnetoresistance (80,000% at 9T, 1.8 K) in bulk single crystals [5]
- To the best of our knowledge, we are the first group to grow single crystal thin films of TaAs

Dual chamber MBE system allows us to integrate topological materials into heterostructures with conventional semiconductors

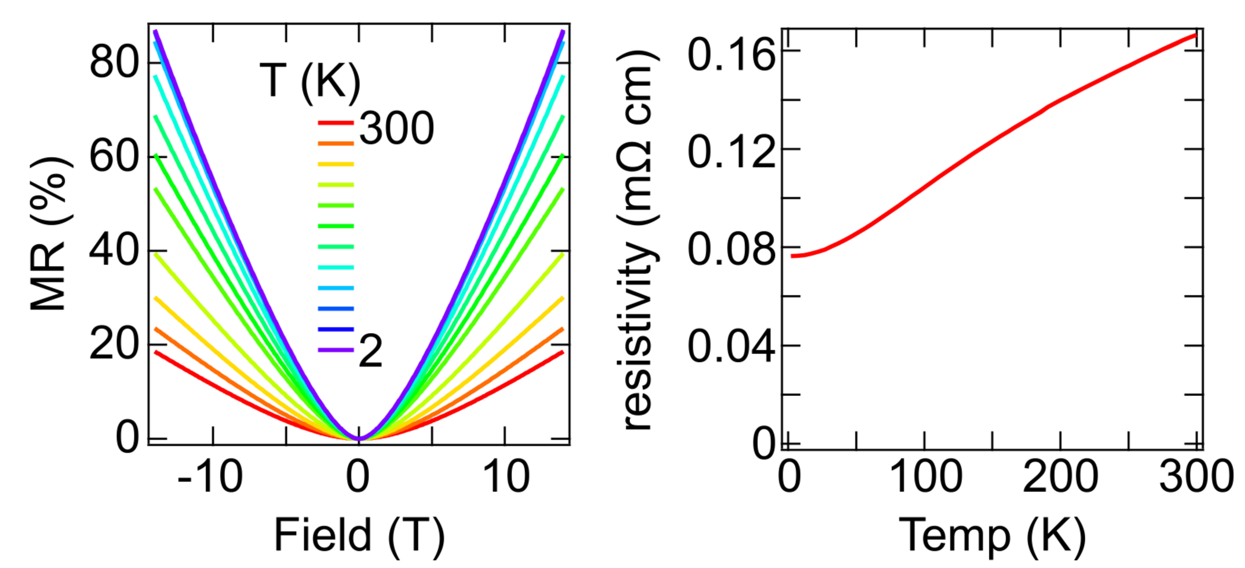


Research Highlights

We have synthesized topological Weyl semimetal TaAs on GaAs(001) substrates by molecular beam epitaxy. Topological semimetals are robust against defects and may enable novel low energy devices. This work lowers the barrier to utilizing them.

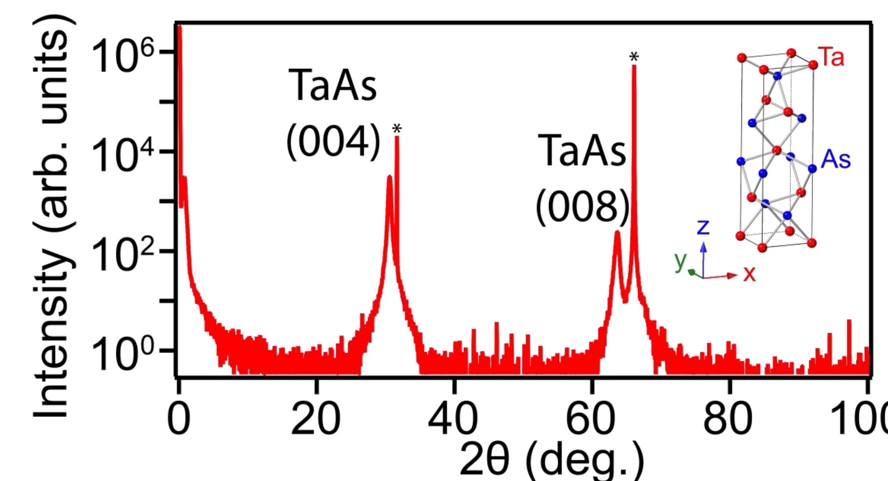


Transmission electron microscopy image of single crystal, single phase epitaxial thin films of TaAs(001)/ GaAs(001)

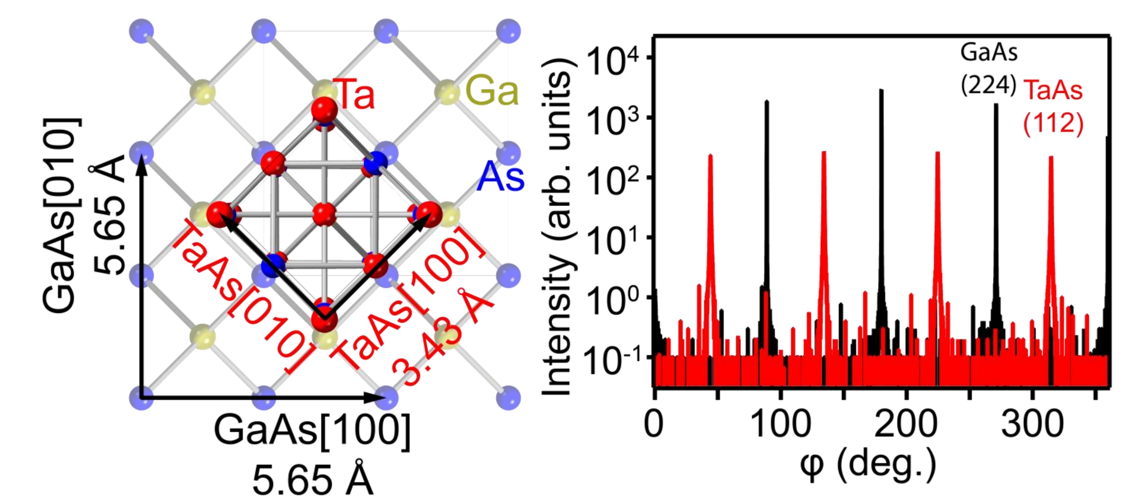


Film displays 80% increase of resistance in magnetic field, metallic resistivity and Mobility > 1000 $cm^2V^{-1}s^{-1}$

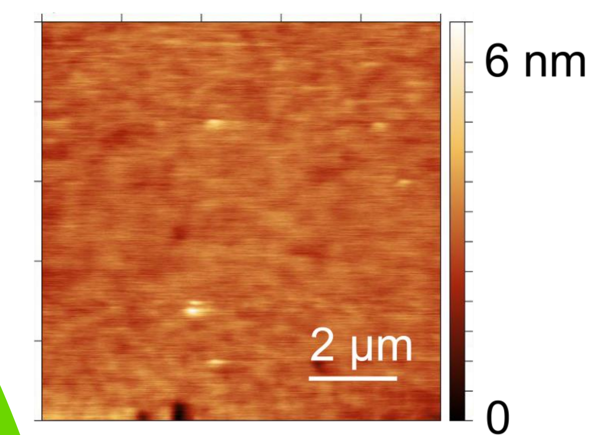
Thin film growth



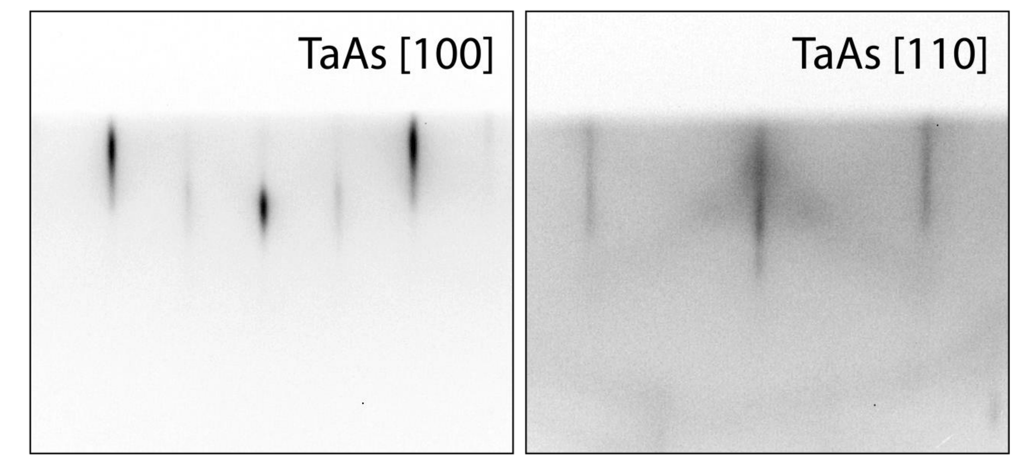
X-ray diffraction shows phase pure films – an important criteria to investigate the properties of TaAs and build devices



Phi scan shows that TaAs is epitaxially oriented relative to GaAs and contains no twin domains



Atomic force microscopy shows smooth surface → films can be incorporated into heterostructures



In situ reflection high-energy electron diffraction images show that film is single crystal

Discussion

- We report the first single crystal, single phase growth of TaAs
- This is a new platform for materials science and microelectronics development
- Thin film platform allows us to fabricate devices
- GaAs(001) substrates are commonly used in manufacturing – use of this substrate decreases the barrier for using Weyl semimetals in applications
- Control of dimensionality using precise MBE growth allows us to explore new physics by confining electrons
- Ongoing work includes exploring device applications in spintronics, catalysis and quantum information

References:

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