Spin-functional materials with atomic layer precision

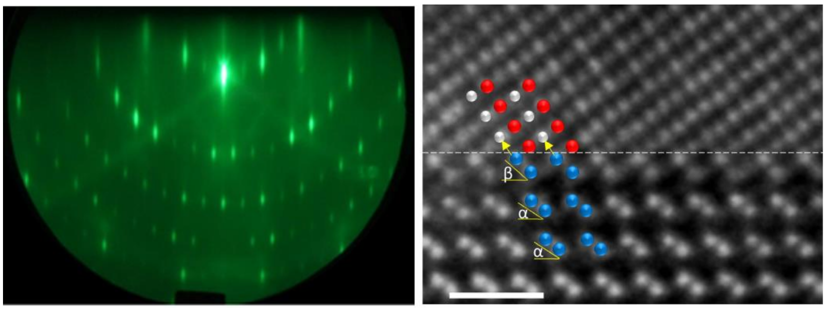
Supervisor: Dr. Gavin Bell

Summary

This experimental PhD project will focus on new materials for spintronics, produced with atomic layer precision by molecular beam epitaxy (MBE). You will use MBE systems at Warwick with in situ analysis capabilities to probe the atomic and electronic structure of the ultra-thin crystalline films. This work will be supplemented by X-ray and neutron measurements performed at central facilities in the UK and France, and by advanced electron microscopy. Our goal is to control the atomic structures of the materials by optimising MBE conditions and correlate these structures with the spintronic properties.

Background

MBE is a technique for growing materials one atomic layer at a time. It is routinely applied for the growth of semiconductor materials, where complex layer structures, such as quantum cascade lasers, can be produced with extraordinary precision. However, materials with other properties such as ferromagnetism, half-metallicity, non-trivial topology or superconductivity can also be grown by MBE. In Warwick we are able to combine state-of-the-art semiconductor growth (both group IV and III-V materials) with exploratory MBE growth of new materials combinations. You will work on the latter, using MBE systems with a suite of in situ analytical tools such as electron diffraction, scanning tunnelling microscopy and electron spectroscopy. These tools allow both the atomic structure and electronic band structure of *pristine* films to be analysed (avoiding degradation by atmospheric contamination). We complement in situ characterisation with ex situ studies of the buried interfaces by neutron and X-ray scattering and advanced scanning transmission electron microscopy (STEM).



Left: in situ electron diffraction of ultra-thin film paramagnetic breithauptite grown by MBE. **Right:** ex situ STEM image of optimised Ge / Heusler alloy interface (scale bar 0.7 nm). Atomic columns are resolved: one can even measure tilting of the uppermost Ge "dumbells".

PhD project: Materials and Collaborations

We will focus on **half-metallic alloys** (100% spin-polarised) grown on Ge and InSb substrates: these are highly promising for semiconductor spintronics and high-speed quantum information processing respectively. Example data are shown in the figure [STEM image from Scientific Reports (2016) 6:37282, DOI: 10.1038/srep37282]. We have shown that highly perfect interfaces are achievable for Heusler alloy / Ge(111) MBE growth which maintain 100% spin polarisation. This work involves collaboration with X-ray and neutron facilities (Diamond Light Source & ISIS in the UK, ESRF & ILL in France), the SuperSTEM facility and the universities of York and Cardiff.

A second research strand will be **topological insulators**, again collaborating with Diamond Light Source, with the aim of optimising MBE growth and understanding the surface and interface atomic structures. Our recent work has shown exciting (and puzzling!) electrical transport behaviour in a very simple MBE-grown system, where the atomic interface structure clearly controls the electrical transport. We suspect that topological surface states play a critical role.

This **Materials Physics Doctorate** project would suit students interested in experimentally-focused research on advanced materials, spintronics, nano-physics and surface science.