

Seeking the ability to design, control and build new materials at the level of individual atoms

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Atomium. Credit: Eddy Van 3000

The ability to design, control and build new materials at the level of individual atoms could open up a whole new world of electronic devices.

Making a perfectly flat layer of billiard balls is fairly straightforward. Doing the same thing with atoms is rather more difficult. But as we demand more of materials, the ability to control atoms as if they were billiard balls is required to make the next generation of advanced materials possible.

Researchers in Cambridge are bringing these 'made-to-measure' materials one step closer to practical applications, and soon they will do so at unprecedented levels, thanks to a new pulsed laser deposition (PLD) system – unique in the UK – that allows for atom-by-atom design and growth.

Oxides are prime candidates for making these new applications possible. Complex oxides – compounds of oxygen and one or more metallic elements – potentially have new properties that surpass those of silicon-based electronics. These make them ideal for next-generation computing devices that process vast amounts of data in an energy-efficient way.

However, it's extremely difficult to control the growth of [complex oxides](#) at the atomic level. To achieve this, new methods of laying down atoms need to be found, and any defects in the materials need to be minimised or eliminated.

Defects influence the electronic properties of a material. In conventional [electronic devices](#), information is carried via the charge or spin on electrons, so anything interfering with the electrons will affect the material's performance. Atoms located in the wrong place or missing entirely can snare electrons like a mouse in a trap. The number of defects that can be tolerated varies depending on the application. Semiconductors, for instance, need to be as close to perfection as possible: the maximum amount of imperfection that can be tolerated is roughly equivalent to a pinhead on a football pitch.

"Designing and growing new materials at the atomic scale are not yet 'made-to-measure' processes," said Professor Judith Driscoll of the Department of Materials Science and Metallurgy, who specialises in fine-tuning the properties of oxides for applications in energy, low-energy electronics and photovoltaics. The properties of oxide materials can be manipulated by changing the bond lengths or angles between atoms, but

cost-effectively designing them to be as close to perfect as possible is not easy.

"Over the past 15 years, we've made huge advances with making materials perfect at nanometre-length scales, but we still can't easily understand things going on at the atomic scale. You assume that things are perfect, but in reality they are not, and you don't know by how much – you can only infer it from indirect measurements. To make really perfect structures, you have to be able to control the number of [atoms](#) being deposited and to stop at the exact point that a single complete layer has been grown."

Most metal oxides are grown using thin-film deposition techniques, where atomic layers are built one on top of the other on a substrate. Thin-film techniques are used by several Cambridge research groups who are interested in the physics and chemistry of functional materials, and how they can be manipulated. For instance, in the Department of Physics, researchers are using these techniques to explore the quantum properties of semiconductors. In Materials Science, Professor Neil Mathur's group uses thin films to study the electrical and magnetic properties of materials, for example attempting to control either their temperature or their magnetism through voltage; and Professor Mark Blamire's group is using them to create new kinds of magnetic and superconducting devices.

While thin-film techniques such as 'sputtering' (eroding material from a source onto a substrate) have been vital in getting [advanced materials](#) such as [metal oxides](#) to their current state, they do not provide either the level of control that's needed to see them used in practical applications nor the capabilities to make them at scale, as Blamire explained:

"Sputtering is a very flexible and accurate technique for many types of metals, but it is not particularly well-suited to single-crystal oxide thin films. We have invested heavily in pulsed laser deposition, but the

thickness control and the range of materials which can be grown is still limited."

Now, Driscoll, along with colleagues in Materials Science and the Department of Physics, has secured funding from the University and the Engineering and Physical Sciences Research Council for state-of-the-art new PLD equipment that will make 'made-to-measure' materials possible. The new system uses advanced PLD with reflective high-energy electron diffraction to control growth rate and produce single atomic layers with a minimum of defects.

The technique will give researchers the capability to measure thin-film thicknesses with extremely high levels of accuracy – down to less than one nanometre in thickness – as well as the ability to perform in situ chemical analysis to ensure the materials and the surfaces they are creating have the intended chemical and electronic structures.

"In addition to helping us build really useful things from oxides, this new technology will help us to discover and explore the properties of [new materials](#)," added Driscoll. "It will take some long-term thinking to see them transition to practical applications, but once we achieve control over these [materials](#) at the [atomic scale](#), the practical applications will follow. We believe that such oxides could really revolutionise electronics."

Provided by University of Cambridge

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