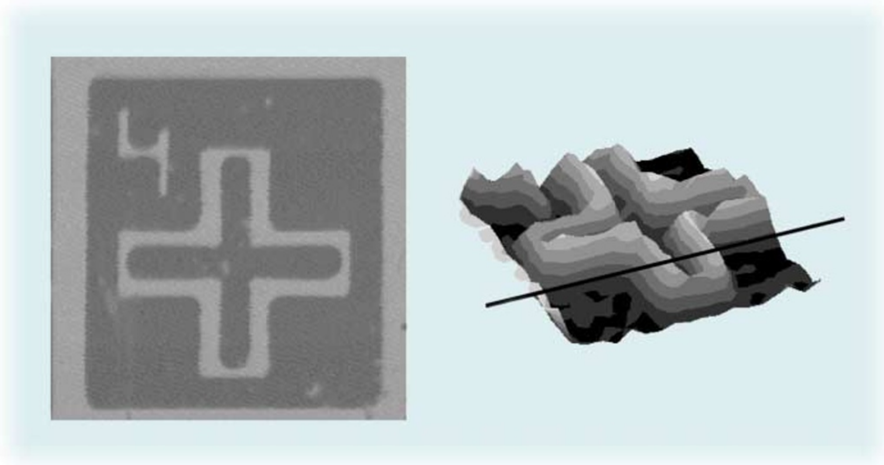
The positron probe

Beams of antimatter are providing some of the most detailed images yet of defects in semiconductors. Philip Ball reports.



Revealed: platinum (dark areas) and oxidized silicon in a 120-micrometre cross imaged by the probe.

An antimatter microscope sounds like an unlikely prospect. Microscopes that use beams of light or electrons to examine materials are well known devices. But matter and antimatter annihilate each other on contact, which makes an antimatter beam sound like a tool for destroying a sample, not studying it.

But in a paper published last month (*Phys. Rev. Lett.* **87,** 067402; 2001), Werner Triftshäuser and his colleagues at the University of the German Federal Armed Forces near Munich describe how they used a beam of antimatter particles to search for defects in a semiconductor. Their microscope, which uses positrons — the positively charged antiparticle equivalents to electrons — has attracted the attention of material scientists and electronic engineers because it can detect defects with a sensitivity of one part in a million.

At the atomic scale, most semiconductors consist of a repeating pattern of atoms. Defects are areas where this regular pattern is disrupted. Some types of defect can limit a semiconductor's ability to conduct electricity. If the number of these defects is too high, microchips made from the semiconductor will be useless.

Damage limitation

Around half of all the defects that damage semiconductors are vacancies — points in the lattice where an atom is missing. These vacancies can reduce the conductivity of a semiconductor by disrupting the flow of the electrons, and detecting them is a big challenge. Electron microscopes can provide nanometre-scale (10^{-9} metres) images of a surface, but they cannot detect vacancies. Other methods can identify vacancies at spatial resolutions of about a millimetre. Triftshäuser's device, although not able to spot individual vacancies, is the first probe to work at microscopic resolutions.

In the new microscope, a pulsed beam of positrons is trained on the sample being studied. Positrons that enter the material are attracted towards electrons and repelled by atomic nuclei. The repulsion by nuclei means that many of the positrons diffuse into vacancies where nuclei are missing.

Ultimately, all of the positrons will encounter an electron and be annihilated, usually within a few hundred picoseconds (a picosecond is 10^{-12} seconds). But because most electrons in a semiconductor are localized around atomic nuclei, there are fewer

Antimatter architects: Werner Triftshäuser (left) and the team behind the positron probe (top).

electrons at vacancy sites than occupied sites. So a positron in a vacancy takes longer to meet and annihilate with an electron. This allows the researchers to use the lifetimes of the positrons to measure the number of vacancies — the longer the average lifetime, the higher the number of vacancies.

Lifetimes are measured by recording the delay between firing a pulse of positrons and detecting the gamma rays emitted as the result of positron–electron annihilations. But the short lifespan of the positrons means that the input pulses need to be just a few hundred picoseconds long. The positrons in Triftshäuser's microscope are derived from a radioactive sodium isotope and are then bunched into 200-ps pulses.

Sensitive scans

The Munich team demonstrated the microscope's sensitivity by detecting vacancies around a 75-micrometre-wide scratch in the surface of a gallium arsenide wafer, a commonly used semiconductor. They found that clusters of vacancies surrounded the scratch. Positrons survived for around 230 ps in defect-free areas, but lasted about 100 ps longer at the scratch's edge.

The microscope also has some capacity to differentiate between different elements. The team used it to scan a cross-shaped pattern of platinum, 120 micrometres wide, that lay on an oxidized silicon wafer. The new probe revealed previously unseen clusters of vacancies beyond the tip of the scratch.

The low intensity of the Munich team's positron beam means that a lot of pulses are needed to generate an image — it can take up to an hour to obtain a single pixel of the final picture. The researchers expect to improve on this by a factor of between 1,000 and 10,000 by using a more intense source from a nuclear reactor. The probe's spatial resolution, which depends on the diameter of the positron beam, will also be improved. The resolution is currently around 2 micrometres, but the team says that this could reach about 50 nanometres within the next five years.

The Munich researchers predict that their microscope will aid investigations into why manufacturing processes introduce defects into semiconductors and how these go on to damage chip performance. And because the accumulation of vacancies weakens metals by initiating cracks, the technique should find uses in measuring the strength and failure of these materials. The future looks bright for the positron probe. ■

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