# QTC making the most of a novel material

David Bloor

*QTC is Quantum Tunnelling Composite, a remarkable new material discovered by David Lussey in 1997. Since then, the material has been carefully characterised (to understand its composition and how it works), and its first applications have emerged.*
*In this article, David Bloor of Durham University describes how QTC was discovered, and how his team set about exploring this strange new material.*

## How QTC was found

QTC is a **composite material** made from particles of a metal (nickel) embedded in a polymer. Its resistance changes dramatically when it is compressed. Uncompressed, it is an almost perfect electrical insulator. When a force is applied, it conducts as well as a metal.

When David Lussey discovered QTC, he was trying to make a conductive adhesive for use in a security system. Computers would be attached by a wire to an alarm; the glue joining the wire to the computer would be conducting, so that if the wire was detached, the alarm would sound.

David describes himself and what he was trying to achieve:

> I'm not a scientist but I am a practical person with a technical background from the military. When I needed a conductive adhesive and found there wasn't one available, I decided to make one.

To make a conducting adhesive, David mixed metal powders with adhesives in different combinations. One turned out to be very special. When two metal plates were glued together, they did not conduct – the glue between them acted as an insulator. However, when he tried to pull the plates apart, they started to conduct.

> This was very strange and not what I was looking for. So I put that on one side (in fact I threw it on one side!) and it wasn't until some little while later that I thought, 'Well, that was a strange reaction.' I went back and measured it with a meter and found I got something very unusual.

It was not obvious at this stage that the material had commercial possibilities; nor did David understand how the material worked to produce this strange behaviour. So he approached my research group here at the University of Durham to help him make sense of his discovery.


*Pressure-sensitive gloves for an astronaut and iPod controls built into the fabric of your jacket – two uses for QTC.*

## Exploring QTC

When David Lussey first showed me a sample of QTC it was immediately apparent that it was an unusual material for two reasons. First, new materials are usually the product of targeted projects carried out in research and development laboratories. The unexpected discovery of a new material, particularly by someone working on their own, is rare.

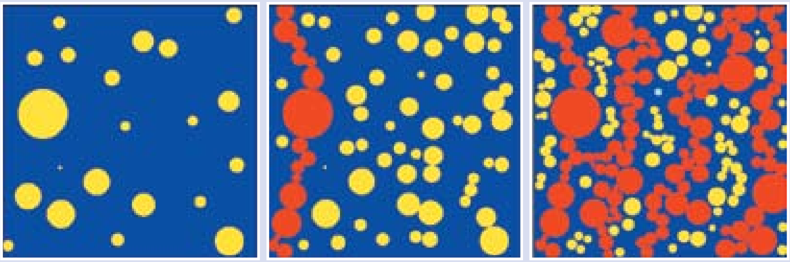
Secondly, QTC behaved differently from other metal-polymer composites. Such materials usually conduct better when compressed, but their resistance rises when they are stretched – see Box 1. QTC becomes conducting when stretched, bent and twisted as well as when compressed!

We set out to understand why QTC is different in two ways:
· by measuring its electrical properties;
· by determining its microstructure.

**Key words**
Composite
Electrons
Resistance
Quantum mechanics

**The microstructure of a material is its structure as seen with microscopes, including very powerful electron microscopes.**

## Box 1



a b c

How does a normal metal-polymer composite conduct electricity?
**a** When the concentration of conductive particles (yellow) in the composite is low, the particles are far apart and the resistance is high, close to that of the binder (blue).
**b** At a critical concentration, particles begin to come into contact and form conducting chains (red) that extend throughout the material. Electrical current can then flow along these chains between the electrodes (green). **c** The resistance falls rapidly as the particle concentration and the number of conductive chains increase. Compression forces more particles into contact giving more conductive chains and the resistance falls. However, when the composite is stretched the particles are pulled apart and the resistance rises. QTC is different – stretching also causes the resistance to fall.

## Electrical properties

A simple measurement shows that the resistance of a small 'pill' of QTC decreases by a factor of $10^6$ as the pressure is increased by a factor of 4 *(figure 1)*.

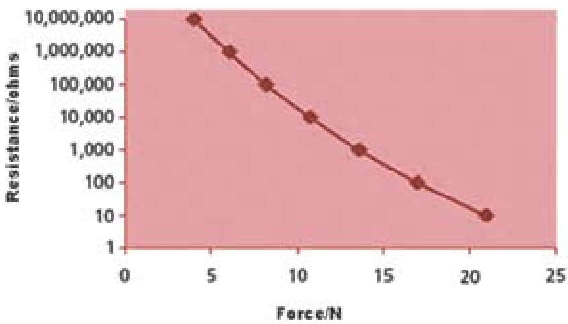



***Figure 1*** *Small increases in force produces enormous changes in the resistance of QTC.*

However, we discovered that when a sheet of QTC was stretched, its resistance fell by a factor of about $10^{10}$, and an even larger effect was observed for compression where the resistance fell by $>10^{14}$, both truly remarkable results.

Measuring such big changes needed special instruments. The resistance of un-deformed samples is very high and requires the measurement of very small currents. We used an electrometer capable of measuring currents down to pico-amperes (1 pA = $10^{-12}$ A). At the other extreme we needed a digital meter capable of accurately measuring milli-ohm resistances.

Measuring the resistance of un-deformed QTC was not straightforward. Tiny forces can alter its resistance, so simply putting wires into contact with QTC can affect the measured resistance. To overcome this problem a layer of QTC was cast between aluminium foils, which did not produce any strain in the sample.

Also, when a force is applied, it takes some time for the resistance to change to a stable value. This is because the material undergoes 'creep' – the applied force causes the individual polymer chains to slowly disentangle.

## Inside QTC

We used two types of electron microscope to study the microstructure of QTC, a scanning electron microscope (SEM) and a transmission electron microscope (TEM).

The TEM images showed that the nickel (Ni) particles were covered in sharp edges and spikes. The SEM images showed a large number of particles all covered in a closely adhering coat of silicone rubber (Figure 2). How can these observations account for the strange properties of QTC?

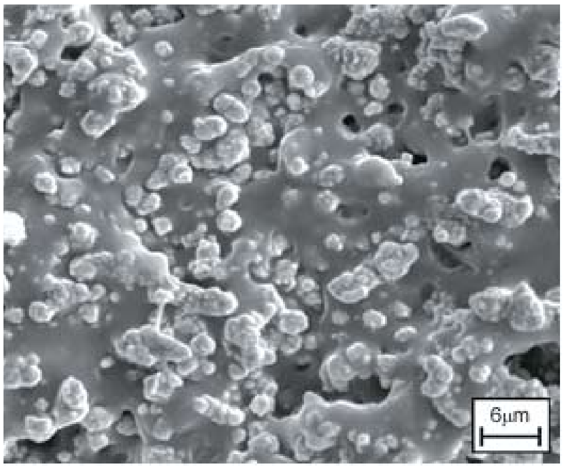



*Figure 2 A scanning electron microscope image of QTC shows the sharply-pointed nickel particles embedded in rubber.*

The polymer coating on the Ni particles prevents them coming into direct physical contact, preventing electrons from hopping from one metal particle to the next. This explains why the initial resistance of QTC is high, despite the high concentration of metal powder.

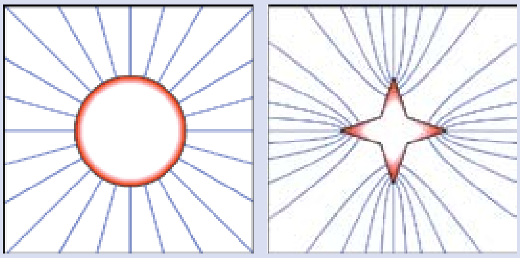
The sharp projections on the Ni particles are vital. Electrons collect at such sharp points, producing a strong electric field (see Box 2). This has an effect because electrons are quantum particles; their behaviour was not understood until the invention of quantum mechanics. An electron can 'tunnel' through a high-resistance barrier provided the barrier is very thin – of the order of nanometers. The thinner the barrier and the more energetic the electrons, the easier it is for them to tunnel through.

The strong electric field at the sharp tips makes the barrier appear thinner to the electrons, and it also gives the electrons more energy. When QTC is deformed, points on neighbouring particles come closer together. Energetic electrons emitted from the tips can 'tunnel' through the relatively thick polymer barriers between the particles, and this explains the low resistance values we found for deformed QTC.

To establish the importance of the sharp features on the Ni particles, we made samples with more rounded particles. The smoother the particles, the less the material's resistance changed when deformed.

***Above:*** *QTC is used in the keys of this roll-up keyboard; to increase the speed of the drill, grip the body more tightly.*

### Box 2



**a** **b**

How do electrons spread themselves over the surface of a metal particle?

**a** For a spherical particle, the charge (shown in red) is distributed uniformly over the surface giving rise to a uniform electric field, shown by the blue lines, outside the particle.

**b** For a non-spherical particle, most charge is on the extremities. The external electric field is strongest at the tips of the sharpest features – perhaps 10,000 times as large as on the surface of a sphere. Such large fields can cause electrons to be emitted from tips, an effect that is utilised in plasma TVs and lightning conductors.

## The future

As QTC is a new material the study of its properties is still in its infancy. The measurements described here were the first steps taken in a programme of research and development that will continue into the future.

*David Bloor is professor of Physics at Durham University.*

### Look here!

Peratech – the company set up to manufacture QTC: www.peratech.co.uk

David Bloor's research group has a website to explain its work: www.dur.ac.uk/psm.group/qtc.html

**Other possible uses for QTC:**

as a sensor in tactile gloves, for disabled people, or for robots

as a sensor in a dance mat, linked to a computer

in pressure sensitive bandages, to avoid squashing the patient

***Left:*** *This jacket has built-in QTC controls for an MP3 player*