High-Field Superconductors under Strain

Jack Craig, Ruby Slinger, Bakir Husremovic

Superconductors

Superconductors are materials which can carry an electric current without resistance. In the case of high-field superconductors, they specialize in carrying very high currents and having a very strong magnetic field. This is useful in creating very powerful electromagnets which are useful in fusion energy, high energy physics research (e.g. CERN) and medicine. (1)

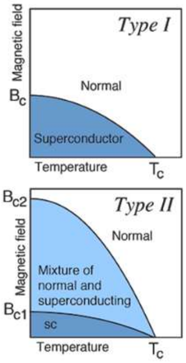


Figure 1 – The difference between type I and type II superconductors (2)

Meissner Effect

All high field superconductors are considered type-II superconductors. This means that they expel their magnetic field (Meissner effect – Figure 2) up to the first critical point, after which they start letting the field penetrate through the surface. The state between the two critical points is the mixed state. After the second critical point, they stop superconducting altogether. (3)

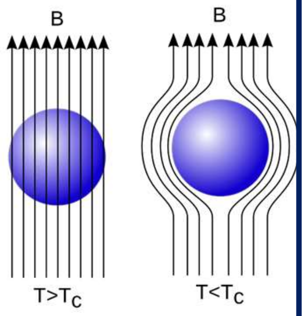


Figure 2 – The Mesissner effect for Type-1 superconductors (4)

What affects superconductivity?

The major parameters that affect superconductivity are temperature, magnetic field and current density. We can also see the Lorentz force acting on the superconducting material itself to cause strain. We are most interested int the critical field H_{c2} which is the maximum magnetic field the material can experience before becoming a norma l conductor. The reason this happens is the movement of fluxons between grains of near-perfect crystal material. This happens due to the Lorentz force from the magnetic field and current pushing them out of this low energy state.

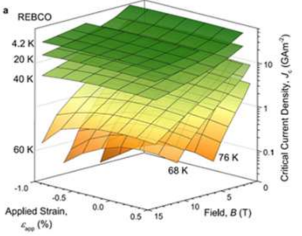


Figure 3 –Shows when REBCO superconducts (5)

Pinning sites

For a perfect system, the Lorentz force acting on the mangetic flux lines (fluxons) would create an induced voltage; and therefore a resistance. This would increase the temperature of the material and remove its superconducting properties. However, in practice this is not the case. This is due to fluxon pinning at 'pinning sites'. These are most commonly created at the boundary between two grains within a crystal, but also can form as a result of impurities within the material. The fluxons are then attracted to the lower energy state of the pinning sites, and get stuck in them. A force (Fp) is required to remove them from the pinning sites. Since the magnetic fluxons are no longer moving within the current, no induced voltage is created and therefore no resistance. Here we see how this force Fp follows a scaling law: (6)

$$F_{\mathrm{p}} \propto \frac{B_{c2}^{n}}{\kappa^{m}} b^{p} (1-b)^{q}$$

where n, m, p and q are constants and b = B/Bc2.

Definition of critical current density

$$F_p = J_c B$$

Method

A current carrying strip is soldered onto the springboard to keep it stable and in place. While controlling the magnetic field and the temperature, the extension of the superconductor is changed. A current is passed through the superconducting strip, and once a voltage is produced, the critical current has been reached and the material no longer behaves as a superconductor. This is the critical current (Jc) for this specific setup of field, temperature and strain. The springboard, temperature and field strength are then changed for multiple values to show these all affect the critical current of a superconductor. (7)

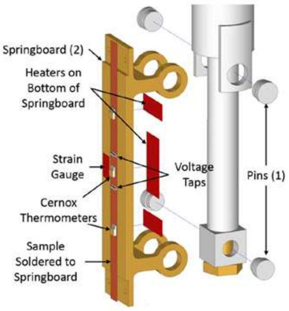
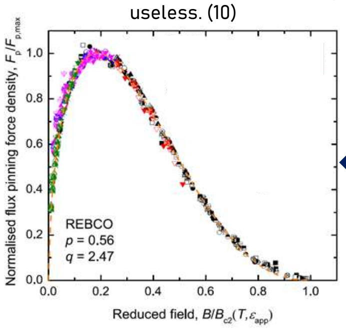


Figure 4 – The experimental set up of the superconductor and the spring board. (8)

Results

The results of the experiment show how the way in which Jc (critical current) varies with Bc2 (critical magnetic field strength) and Tc (critical temperature), as is shown through the equation at the centre, regardless (up to a point) of the amount of strain the system is under. If the strain placed on the system becomes too high however, we see how the grains of the superconductor can become distorted and the material loses its superconductivity, rendering it useless. (10)



Result graph for REBCO material. We can see how it performs with set parameters p and q.

Figure 5 - Realationship between reduced field and the normalised flux pinning force density for REBCO (9)

References

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Acknowledgements

Many thanks to Paul Branch, Northumbria University and all NUSTEM Physics Experience Week Staff!