Experimental Report

11/04/2014

Proposal: **5-32-789** **Council:** 10/2012

Title: Fundamental investigations of the lattice transition and superconductivity in Nb3Sn by SANS

This proposal is a new proposal

Researh Area: Physics

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Samples: Nb3Sn (4 samples: 2 with 25at% Sn and 2 with 27a5% Sn)

Instrument	Req. Days	All. Days	From	To
D33	8	6	01/08/2013	05/08/2013

Abstract:

Nb3Sn is the superconductor most used for generating the highest magnetic fields, due to its large critical current and Hc2 value, and the ability to create wires in suitable quantities. However, there are still uncertainties about its fundamental properties. Many samples show a lattice instability above Tc, converting the cubic crystal structure into tetragonal. In this respect it foreshadows the very recent observation of charge density wave order appearing above Tc in moderately underdoped YBCO [0]. In both cases, it would be expected that superconductivity and lattice distortion compete, but in Nb3Sn this competition has not been deeply investigated. We wish to study the fundamental superconducting properties of Nb3Sn in a set of well characterized low-pinning samples, by SANS measurements of the flux lattice up to 17 T using our dedicated magnet (which uses Nb3Sn in its windings!)

Fundamental investigations of the lattice transition and superconductivity in Nb_3Sn by SANS

Nb_3Sn is the most widely used superconductor for generating magnetic fields above 10 T. As an example, more than 600 tons will be used in at the ITER facility. It is used because very high critical current densities can be achieved [1], and this can be increased by tuning the Sn content [2] or by doping with impurities. However, somewhat surprisingly, careful studies of the upper critical field, H_{c2}, were only completed recently [3], and they have revealed some unexpected phenomena.

Nb_3Sn has $T_c \sim 18$ K, and undergoes a cubic to tetragonal martensitic transition below $T_M \sim 35$ K [4]. This transition can be suppressed by reducing the tin content below 24.5%, and superconductivity still occurs. However, in the tetragonal phase, the upper critical field was thought to be suppressed (see the review by Godeke [5] for a full discussion of the experimental results). It has even been argued that the superconductivity may be confined to the cubic A15 phase.

In Ref. 3, the authors were able to force samples with high tin concentrations to stay cubic in the superconducting phase by increasing the annealing temperature. The upper critical field as a function of temperature for these samples in the cubic and tetragonal phases was then measured, and found to be the same, indicating that the structural transition does not control the upper critical field.

In this experiment, we examined four polycrystalline samples of volume 5 x 5 x 5 mm^3, containing 25 and 27 at. % of Sn, prepared following the same method as in Ref. 3. A cubic and a tetragonal sample for both percentages was originally intended; however, in the end the 25 at. % samples were both tetragonal, although one had been expected to be cubic (see Table 1). Due to scheduling problems, the ILL 7 T magnet was used instead of the Birmingham 17 T magnet.

Sample number	**At. % Sn**	**Target structure**	**Actual structure**
1	27	tetragonal	tetragonal
2	27	cubic	cubic
3	25	tetragonal	tetragonal
4	25	cubic	tetragonal

Table 1: Samples of Nb_3Sn studied.

Flux lines were observed, as rings of scattering, in all four samples. Figure 1 is a typical example of the data obtained. Figure 2 shows the regions of the phase diagram mapped out for the four samples. The scattering vector of the flux line ring was obtained by fitting the intensity against distance from the detector centre using a 360° sector. This has been mapped as a function of field and temperature. There is little variation with temperature, but as a function of field, the hexagonal vortex lattice clearly distorts to become square. This behaviour is seen in all samples, although there are some small differences between the cubic and tetragonal samples (see Figure 3).

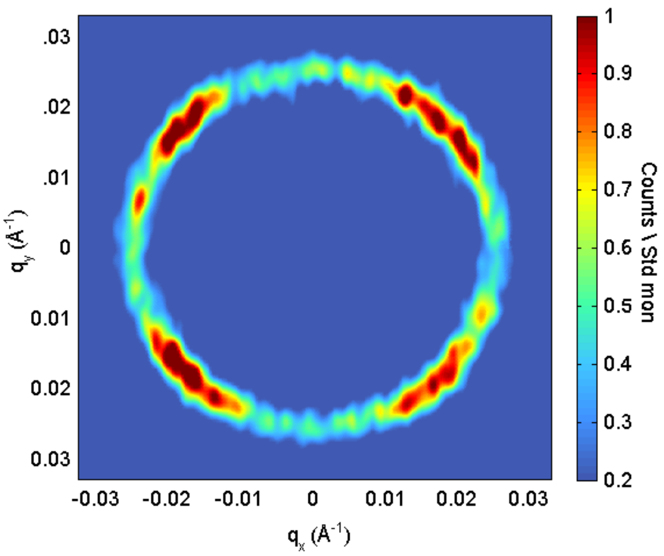

Figure 1: Typical diffraction pattern (this was measured on Sample 2 at 2 K and 3 T). The pattern is the sum of measurements made to rock (in angle) through reciprocal space in the horizontal and vertical directions. This gives rise to the apparent intensity increase on the diagonals, which is an artefact of the summation. The direct beam has been masked out.

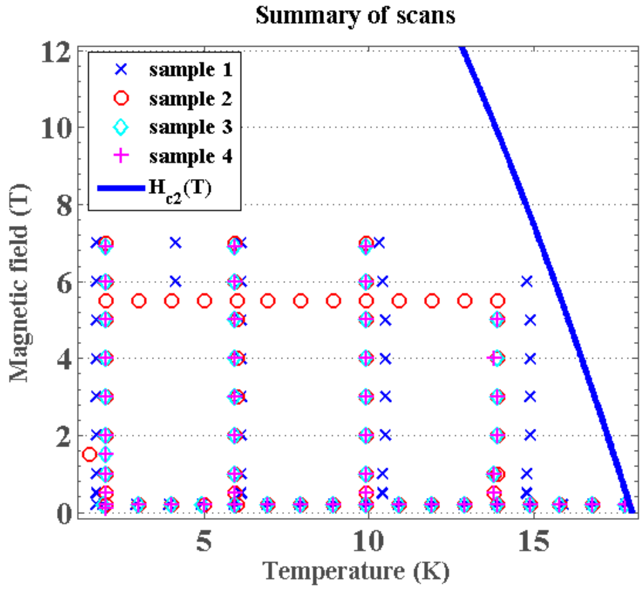

Figure 2: The mapping of the phase diagram carried out in the experiment. Note that H_{c2}(0K)~25T. All points were reached by field cooling from the normal state.

We note that this change from hexagonal to square had previously been observed in single crystals of Nb_3Sn of mass 100 mg using SANS-J at the JRR-3 reactor [6] in fields up to 5 T (limited by the accessible magnetic field rather than sample signal). The flux line lattice changed from hexagonal to square between 2 and 3 T in that experiment, carried out on a sample with tetragonal structure at low temperatures. These results all point towards non-local effects dominating the high field state, most probably due to an anisotropic Fermi surface.

We have also measured the form factor as a function of field and temperature for all of the samples (see Figure 4).

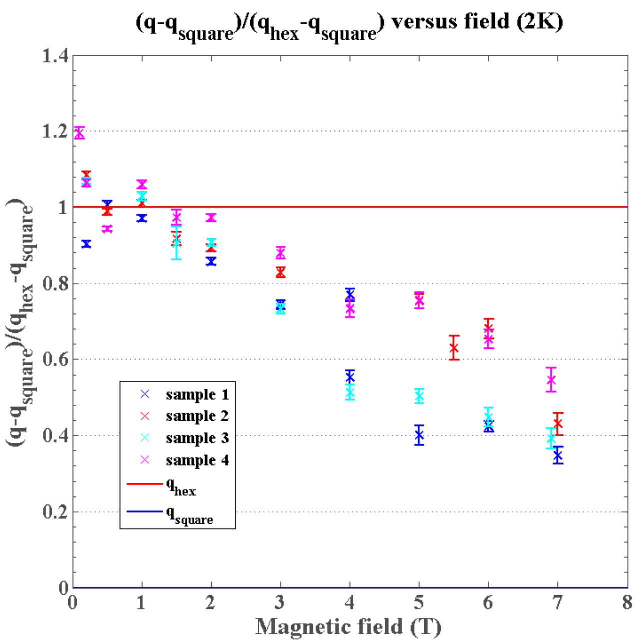

Figure 3: Normalised scattering vector versus applied magnetic field for the four samples measured. The solid lines indicate the wavevector expected for a perfect hexagonal lattice (red) and a perfect square lattice (blue).

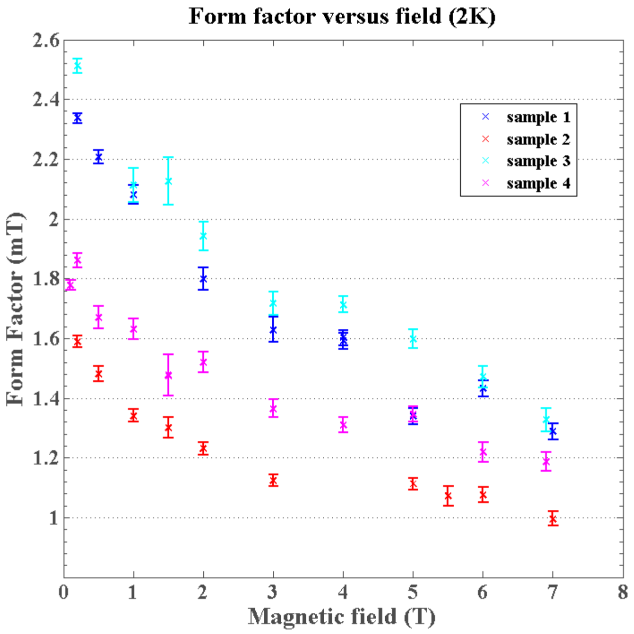

Figure 4: Form factor versus applied magnetic field for the four samples measured.

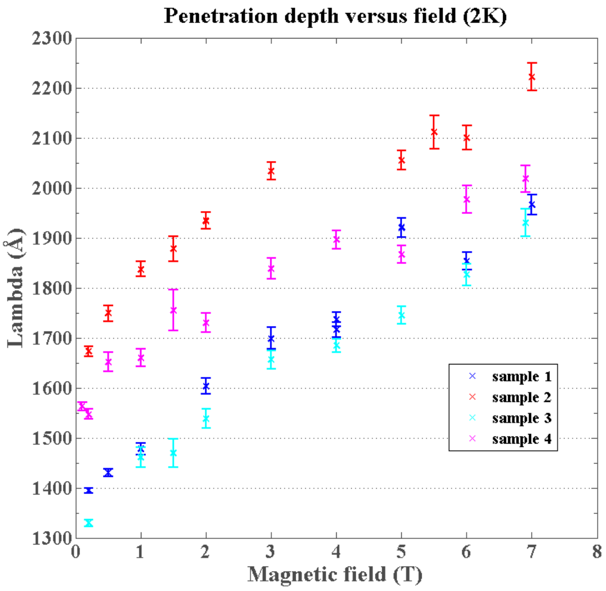

Figure 5: Penetration depth versus applied magnetic field for the four samples measured.

The data show a clear difference between the cubic (red points) and the tetragonal (blue and cyan points), with the sample that was meant to be cubic, but was actually tetragonal, falling between them, interestingly. We are therefore sensitive to changes in the superfluid density brought about by the changes to the Fermi surface. The magnetic penetration depth plotted versus field (Figure 5), calculated from the form factor values (London model), shows the same trend.

References

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