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Weak-links criterion for pnictide and cuprate superconductors

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Abstract

Weak-links are defects that limit dissipation-free transport current flow in superconductors. Grain boundaries, nano- and micro-cracks, and planar precipitations of secondary phases are typical examples of weak-links in practical superconductors. There is an unanswered practical question: is the critical current for a given superconductor limited by weak-links, or does wire fabrication provide a weak-link-free superconductor? In this paper, we answer this question for layered quasi-two-dimensional (quasi-2D) superconductors, namely pnictides and cuprates. Our approach is based on the fact that the self-field critical current density in weak-link-free superconductors is $J_c(\mathrm{sf}, T) = A/\lambda^3(T)$, where $\lambda(T)$ is the London penetration depth and A is the relevant fundamental constant. Taking into account that the transition temperature, T_c, in layered quasi-2D superconductors is limited by the phase fluctuation temperature, $T_{\mathrm{fluc}} = B/\lambda^2(0) \geqslant 1.2 \cdot T_c$, where B is the relevant fundamental constant, then the substitution of $\lambda(0)$ deduced from the measured $J_c(\mathrm{sf}, T)$ gives a tool to compare the deduced T_{fluc} and experimentally measured T_c. This provides a simple criterion to reveal the presence or absence of weak-links which has been proven by an analysis of self-field critical currents in a variety of high-temperature superconductors, ranging from atomically thin FeSe up to commercially available tapes of $RBa_2Cu_3O_7$.

Keywords: critical currents, iron-based superconductors, HTS

(Some figures may appear in colour only in the online journal)

1. Introduction

Weak-links are defects in superconductors that limit their critical currents and have a detrimental effect on the engineering applications of superconducting wire [1]. For several decades, the main tool for investigating weak-links in practical wires made using cuprates, and for the last decade using pnictides, have been microscopic techniques [1–3]. Despite the ongoing research in this field, it is still unclear how to answer one of the most important questions of wire manufacture: how do we determine if weak-links are limiting the current carrying capacity of a given superconducting wire? Here we present an answer to this question for iron-based and cuprate superconductors.

2. Model description

Our approach is based on the recent finding [4] that in weak-link-free thin film superconductors of type-II, the self-field critical current density, $J_c(\mathrm{sf}, T)$, is described by the equation:

$$J_c(\mathrm{sf}, T) = \frac{\phi_0}{4 \cdot \pi \cdot \mu_0} \cdot \frac{\ln(\kappa) + 0.5}{\lambda^3(T)}, \quad (1)$$

where ϕ_0 is the magnetic flux quantum, μ_0 is the magnetic permeability of free space, λ is the London penetration depth, $\kappa = \lambda/\xi$ is the Ginzburg–Landau parameter, and ξ is the coherence length. The annotation 'sf' refers to 'self-field'. Equation (1) can be converted to give:

$$\lambda(T) = \left(\frac{\phi_0}{4\cdot\pi\cdot\mu_0}\cdot\frac{\ln(\kappa)+0.5}{J_c(\mathrm{sf},\,T)}\right)^{\frac{1}{3}}. \quad (2)$$

Recently [5], equation (1) was extended for samples of any width, $2a$, and thickness, $2b$ by using

$$J_c(\mathrm{sf},\,T) = \frac{\phi_0}{4\cdot\pi\cdot\mu_0}\cdot\frac{\ln(\kappa)+0.5}{\lambda^3(T)}\cdot\left(\frac{\lambda(T)}{a}\cdot\tanh\left(\frac{a}{\lambda(T)}\right)+\frac{\lambda(T)}{b}\cdot\tanh\left(\frac{b}{\lambda(T)}\right)\right). \quad (3)$$

For anisotropic superconductors with mass anisotropy $\gamma = (m_c/m_{ab})^{0.5}$, where m_c and m_{ab} are effective out-of- and in-plane masses respectively, the equation for rectangular conductors is:

$$J_c(\mathrm{sf},\,T) = \frac{\phi_0}{4\cdot\pi\cdot\mu_0}\cdot\frac{\left((\ln(\kappa_c)+0.5)\cdot\left(\frac{\gamma\cdot\lambda_{ab}(T)}{b}\cdot\tanh\left(\frac{b}{\gamma\cdot\lambda_{ab}(T)}\right)\right)+\frac{\ln(\gamma\cdot\kappa_c)+0.5}{\gamma^{\frac{1}{2}}}\cdot\left(\frac{\lambda_{ab}(T)}{a}\cdot\tanh\left(\frac{a}{\lambda_{ab}(T)}\right)\right)\right)}{\lambda_{ab}{}^3(T)}. \quad (4)$$

Based on the above, we consider a way to answer the previously posed question for the pnictide and the cuprate superconductors.

It is a well-established fact [7] that the transition temperature, T_c, of quasi-two-dimensional (quasi-2D) superconductors (which includes cuprates and pnictides) is limited by the temperature at which phase fluctuations of the order parameter become significant. The characteristic temperature, T_{fluc}, of these fluctuations is given by Emery and Kivelson [7]:

$$T_{\mathrm{fluc}} = \frac{0.9\cdot\phi_0^2\cdot d_{001}}{4\cdot\pi^2\cdot\mu_0\cdot k_B\cdot\lambda^2(0)}, \quad (5)$$

where k_B is the Boltzmann constant, and d_{001} is the mean spacing between superconducting sheets for quasi-2D systems. It was shown [7, 8] in the case of the cuprates and pnictides that the relation between T_c and T_{fluc} is:

$$T_{\mathrm{fluc}} \geqslant 1.2\cdot T_c. \quad (6)$$

If thin films have thickness, $2b$, less than the London penetration depth in the c-direction, $\lambda_c(0)$, one can substitute equations (1), (2) into equations (5), (6) and find:

$$T_{\mathrm{fluc}} = \frac{d_{001}}{1.76\cdot k_B\cdot\mu_0^{\frac{1}{3}}}\cdot\left(\frac{\phi_0}{\pi}\right)^{\frac{4}{3}}\cdot\left(\frac{J_c(\mathrm{sf},\,T\simeq 0)}{(\ln(\kappa)+0.5)}\right)^{\frac{2}{3}} \geqslant 1.2\cdot T_c. \quad (7)$$

This equation provides a simple route to determine if the weak-links in a given superconductor are reducing the experimentally measured $J_c(\mathrm{sf},\,T)$. If $J_c(\mathrm{sf},\,T)$ has been measured to sufficiently low temperatures, $J_c(\mathrm{sf},\,T = 0\,\mathrm{K})$ can be extrapolated and a comparison of the calculated T_{fluc} can be made with the experimentally measured transition temperature, T_c. If T_{fluc} is larger than T_c, the transport current for that particular superconductor is not limited by weak-links. If the superconductor is affected by weak-links, then $J_c(\mathrm{sf},\,T)$ will be lower than expected and the calculated T_{fluc} will be smaller than T_c.

Equation (7) can also be rearranged to allow calculation of a 'weak-link limit' of $J_c(\mathrm{sf},\,T \sim 0\,\mathrm{K})$ which is given as

$$J_c(\mathrm{sf},\,T\simeq 0\,\mathrm{K}) \gtrsim \frac{\pi^3\cdot\mu_0^{\frac{1}{2}}\cdot k_B^{\frac{3}{2}}}{\phi_0^2}\cdot(\ln(\kappa)+0.5)\cdot\left(\frac{T_c}{d_{001}}\right)^{\frac{3}{2}} = J_{c,\mathrm{2Dfluc}}(\mathrm{sf},\,T\simeq 0\,\mathrm{K}). \quad (8)$$

We now consider superconductors which contain weak-links. The experimentally measured $J_c(\mathrm{sf},\,T)$ for these particular specimens will be lower in comparison with weak-link-free specimens, as weak-links limit transport current flow in superconductors. In this case the *deduced* $\lambda(0)$ (by using $J_c(\mathrm{sf},\,T)$ and equations (1)–(4)) will be larger for weak-link affected samples than for weak-link-free samples. We note that the *actual* $\lambda(0)$ for both types of samples will likely be the same as the presence of weak-links in the material will be unlikely to change $\lambda(0)$. This is because the superfluid density should remain the same dispite the presence of weak-links, but the restriction of supercurrent flow will lead to lower measured values of $J_c(\mathrm{sf},\,T)$ and thus the *deduced* $\lambda(0)$ will be larger than the *actual* $\lambda(0)$.

The simplest approach to detect the presence of weak-links in a superconductor is to compare a deduced $\lambda(0)$ value for a given superconducting wire with $\lambda(0)$ values already reported for this superconducting material measured by other techniques. However, this approach might not work for many practical cases, for example, in the case of newly discovered materials, atomically thin (and exfoliated) superconductors, and exotic superconductors (like compressed H_3S [6]). It may be the case for these examples and others that the application of standard techniques to measure $\lambda(0)$ is questionable, time consuming, or reported $\lambda(0)$ values are within a large interval as the experimental techniques used are not able to determine $\lambda(0)$ with great accuracy.

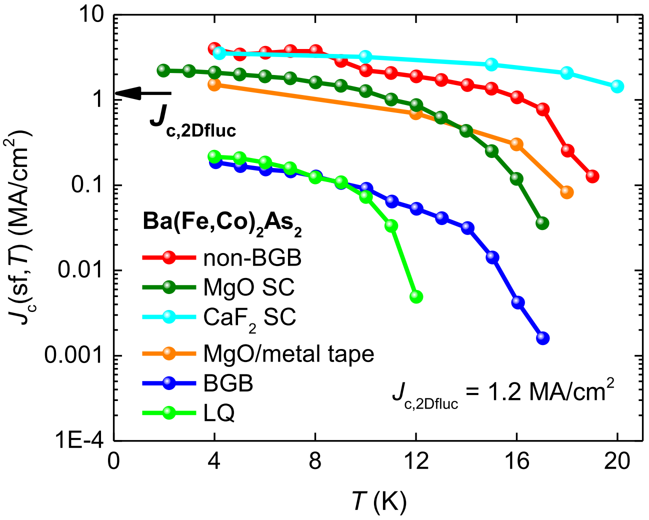

Figure 1. Experimental J_c(sf, T) for Ba(Fe,Co)$_2$As$_2$ films deposited on LSAT single crystal (non-BGB) [12]; on 30°-[001]-tilted bicrystals of LSAT (BGB) [12], and low quality Ba(Fe,Co)$_2$As$_2$ film on LSAT single crystal (LQ) [17]. There are also Ba(Fe,Co)$_2$As$_2$ films deposited on a MgO single crystal (MgO CS) [18], a CaF$_2$ single crystal (CaF$_2$ SC) [19] and on a MgO-buffered metal-tape flexible substrate (MgO/metal tape) [20].

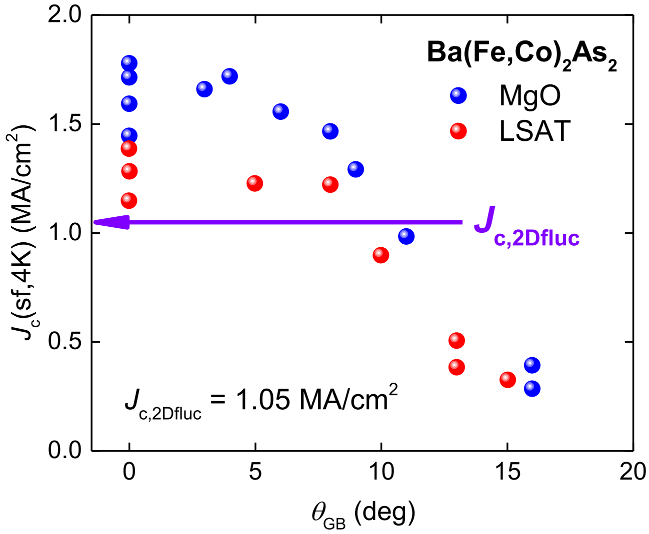

Figure 2. Experimental J_c(sf, 4 K, θ_{GB}) for Ba(Fe,Co)$_2$As$_2$ films deposited on MgO and LSAT [001]-tilted bicrystals [22].

Here if the observed J_c(sf, $T \sim 0$ K) is less than $J_{c,2Dfluc}$(sf, $T \sim 0$ K) then the critical current has likely been affected by weak-links in the sample.

The right-hand side of equation (8) is a function of only fundamental constants (μ_0, k_B, ϕ_0) and material specific parameters (κ, T_c, d_{001}). Within a multiplication pre-factor of the order of unity, equation (8) calculates more or less the achievable J_c(sf, T) value for quasi-2D superconductors where the order parameter phase fluctuations determine the observed T_c value.

The most direct way to test the proposed criterion (equations (7), (8)) is to analyse experimental J_c(sf, T) data reported by the same research group on both weak-link-free samples and samples where weak-links have been deliberately introduced. There are several reports available with this type of experimental data, the results of which will be shown to support the proposed criterion (equations (7), (8)) for pnictide and cuprate superconductors.

This means that knowledge of κ, d_{001} and T_c for any quasi-2D superconductor will be enough to make a judgement on the desirability of doing further work to reduce weak-links in the material (which will in general require a very significant research and development (R&D) investment [9–11]), as equation (8) provides an estimate of the achievable self-field critical current capacity for a given material.

3. Results

3.1. Iron-based superconductors

3.1.1. Ba(Fe,Co)$_2$As$_2$. Katase *et al* [12] have reported J_c(sf, T) data for high-quality epitaxial Ba(Fe,Co)$_2$As$_2$ films ($2a = 10\ \mu$m and $2b = 250$ nm). The films were deposited by pulsed laser deposition on single crystals of (La,Sr)(Al,Ta)O$_3$ LSAT (non-BGB) as well as 30°-[001]-tilted bicrystal (La,Sr)(Al,Ta)O$_3$ (LSAT) substrates (BGB). The film thickness was less than the c-axis London penetration depth for Ba(Fe,Co)$_2$As$_2$, $\lambda_c(0) = 1\ \mu$m [13, 14], and thus by substituting the observed $T_c = 22.6$ K [12], the distance between FeAs layers, $d_{001} = 0.65$ nm [15, 16], and $\kappa = 90$ [13, 14] into equation (8), one can calculate that $J_{c,2Dfluc}$(sf, $T \simeq 0$ K) $= 1.2$ MA cm^{-2}.

In figure 1 we show experimental J_c(sf, T) reported by Katase *et al* [12] for both films. Also in figure 1 we show J_c(sf, T) data for a low quality Ba(Fe,Co)$_2$As$_2$ film which was synthesised and studied by the same research group in a different report [17]. This low quality film is obviously affected by weak-links as J_c(sf, $T = 4$ K) $\ll 1.2$ MA cm^{-2} as well as being less than the J_c(sf, $T = 4$ K) of the other films.

Mohan *et al* [21] reported J_c(sf, T) data for similar Ba(Fe,Co)$_2$As$_2$ films deposited on MgO single crystals, for which J_c(sf, $T = 2$ K) $= 2.2$ MA cm^{-2} (figure 1). Also, Katase *et al* [20] reported J_c(sf, T) data for Ba(Fe,Co)$_2$As$_2$ films deposited on biaxially textured MgO-buffered metal-tape flexible substrates, where J_c(sf, $T = 4$ K) $= 1.5$ MA cm^{-2} (figure 1), which is just a little higher than the calculated $J_{c,2Dfluc}$(sf, $T \sim 0$ K).

Yuan *et al* [19] reported J_c(sf, T) data for Ba(Fe,Co)$_2$As$_2$ deposited on a CaF$_2$ single crystal substrate. These films have a relatively large transition temperature of $T_c = 26$ K with a corresponding value $J_{c,2Dfluc} = 1.7$ MA cm^{-2}. This is about 50% larger when compared with $J_{c,2Dfluc}$(sf, $T \sim 0$ K) calculated for the other films, however, the experimental J_c(sf, T) data for Ba(Fe,Co)$_2$As$_2$ on a CaF$_2$ substrate (figure 1) is well aligned with the best films on LSAT single crystals.

As we can see in figure 1, our expectation (equation (8)) that weak-link-free films should have J_c(sf, $T \sim 0$) $> J_{c,2Dfluc}$(sf, $T \sim 0$) and weak-linked films should have J_c(sf, $T \sim 0$) $< J_{c,2Dfluc}$(sf, $T \sim 0$) was confirmed by an analysis of the Ba(Fe,Co)$_2$As$_2$ film data.

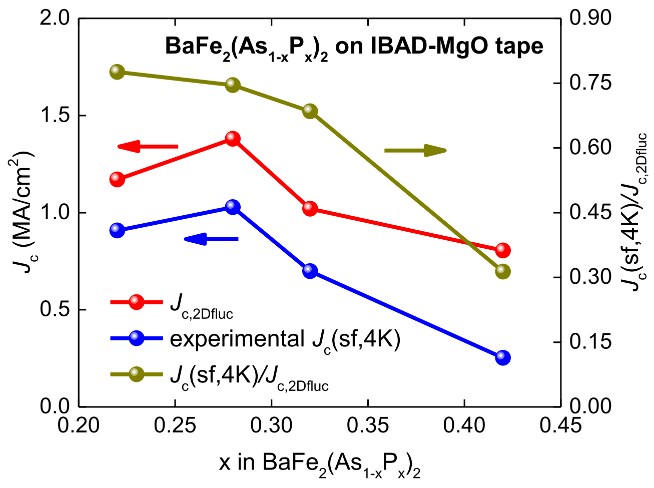

Figure 3. The dependence of $J_c(\mathrm{sf}, 4\ \mathrm{K})$, $J_{c,2Dfluc}(\mathrm{sf}, T \sim 0\ \mathrm{K})$ and their ratio for $BaFe_2(As_{1-x}P_x)_2$ ($x = 0.22 - 0.42$) films grown at the optimum $T_s = 1050\ ^\circ C$ on practical IBAD–MgO metal-tape substrates [24].

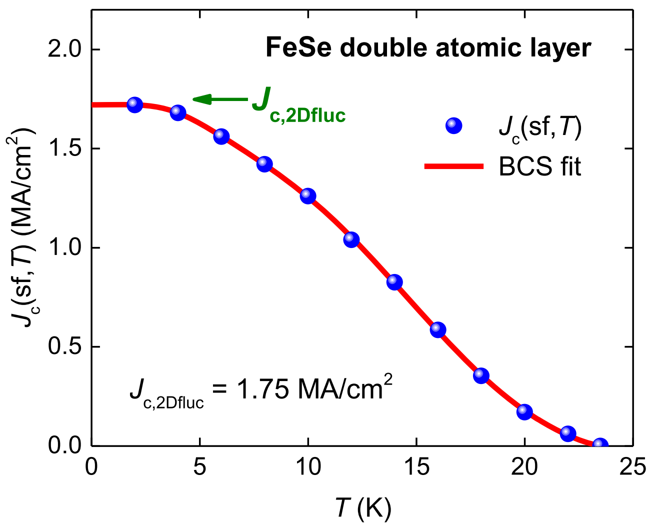

Figure 4. Experimental $J_c(\mathrm{sf}, T)$ (reported in [27]) for a double layer FeSe film.

Another question to consider is what critical grain boundary angle, $\theta_{GB,c}$, will cause $J_c(\mathrm{sf}, T)$ to reduce below $J_{c,2Dfluc}$. To answer this question in figure 2 we plotted $J_c(\mathrm{sf}, 4\ \mathrm{K}, \theta_{GB})$ data reported by Hiramatsu *et al* [22] for $Ba(Fe,Co)_2As_2$ films. The observed T_c for these films was 19.1 K and an evaluation of equation (8) gives the value $J_{c,2Dfluc}(\mathrm{sf}, T \simeq 0\ \mathrm{K}) = 1.05\ \mathrm{MA\ cm^{-2}}$.

Based on the experimental data shown in figure 2 we can conclude that $\theta_{GB,c} = 10°$. This result is agreement with a report by Sato *et al* [23], who showed that for $BaFe_2(As_{1-x}P_x)_2$ films deposited on poorly aligned (8°) polycrystalline metal-tape substrates, $J_c(\mathrm{sf}, T)$ does not degrade in contrast with films deposited on well aligned (4°) substrates.

3.1.2. $BaFe_2(As_{1-x}P_x)_2$ ($x = 0.22 - 0.42$).

The next iron-based superconductor on which we test our idea is $BaFe_2(As_{1-x}P_x)_2$ deposited on practical ion beam assisted deposition (IBAD)–MgO metal-tape substrates as reported by Hiramatsu *et al* [24]. Bulk $BaFe_2(As_{1-x}P_x)_2$ exhibits a significantly higher maximum $T_c \sim 31$ K [21] when compared with $Ba(Fe,Co)_2As_2$ ($T_c \sim 22$ K [12, 17–20, 22]).

However, thin films on IBAD–MgO metal-tape substrates have a lower transition temperature in comparison with bulk samples [24]. A question can be asked here: are $BaFe_2(As_{1-x}P_x)_2$ films deposited on practical IBAD–MgO metal-tape substrates affected by weak-links or is some other factor playing a role in suppressing the superconducting properties.

To answer this question, we calculate $J_{c,2Dfluc}(\mathrm{sf}, T \sim 0\ \mathrm{K})$ for all samples reported by Hiramatsu *et al* [24], noting that the change of d_{001} versus phosphorus concentration is small [21] and therefore assuming $d_{001} = 0.635$ nm for all compositions. In figure 3 we present the results. Despite the different film compositions, the ratio of $J_c(\mathrm{sf}, T = 4\ \mathrm{K})/J_{c,2Dfluc}(\mathrm{sf}, T \sim 0\ \mathrm{K})$ remains relatively constant at 0.7–0.8 for $x \leqslant 0.32$. This suggests that the effect of the weak-links is similar across these films, which is could be due to the use of the same substrate.

The results in figure 3 show that:

1. A further 30%–50% improvement in the critical current is still possible for $BaFe_2(As_{1-x}P_x)_2$ deposited on practical IBAD–MgO metal-tape substrates.
2. The fundamental performance of the wire is better at lower phosphorus concentrations, and it is likely that it will be easier to create weak-link-free superconducting wire with a lower phosphorous content, rather than focusing on higher phosphorous concentrations.

3.1.3. FeSe single/double atomic layer films.

We now turn to a most fascinating iron-based superconductor, FeSe. Understanding the physics of this chemically simple compound has proven to be a difficult task. One example of its remarkable properties was discovered by Wang *et al* [25], who found that reducing down to a single or double layer of FeSe causes a notable increase in the transition temperature, reaching $T_c = 100$ K [26] in the case of a single FeSe atomic layer.

The crystalline structure of FeSe is described elsewhere [27] where the distance between FeSe atomic layers was found to be $d_{001} = 0.553$ nm [27]. It also has a Ginzburg–Landau parameter of $\kappa = 72$ [28].

In figure 4 we show $J_c(\mathrm{sf}, T)$ for a double layer of FeSe reported by Zhang *et al* [27] with a current bridge width of $2a = 1.45$ mm. The observed superconducting transition temperature of this FeSe film was $T_c = 23.5$ K [27]. The $J_c(\mathrm{sf}, T)$ of this film has already been analysed in our previous paper [29], with the resulting fit shown in figure 4.

A calculation of the weak-link-free critical current density of this film gives $J_{c,2Dfluc}(\mathrm{sf}, T \simeq 0\ \mathrm{K}) = 1.75\ \mathrm{MA\ cm^{-2}}$. The experimental $J_c(\mathrm{sf}, T)$ data [27] as well as the fit to our model [5, 29] closely match giving $J_c(\mathrm{sf}, T = 2\ \mathrm{K}) = 1.73\ \mathrm{MA\ cm^{-2}}$. This means that the atomically thin FeSe films fabricated by

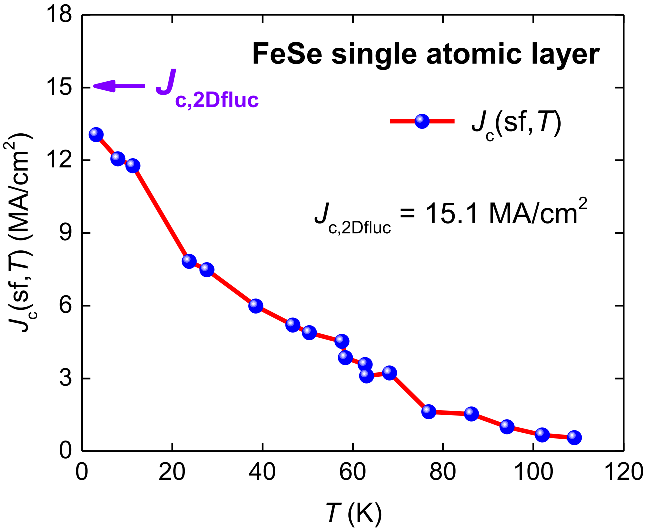

Figure 5. Experimental J_c(sf, T) (reported in [26]) for single atomic layer FeSe.

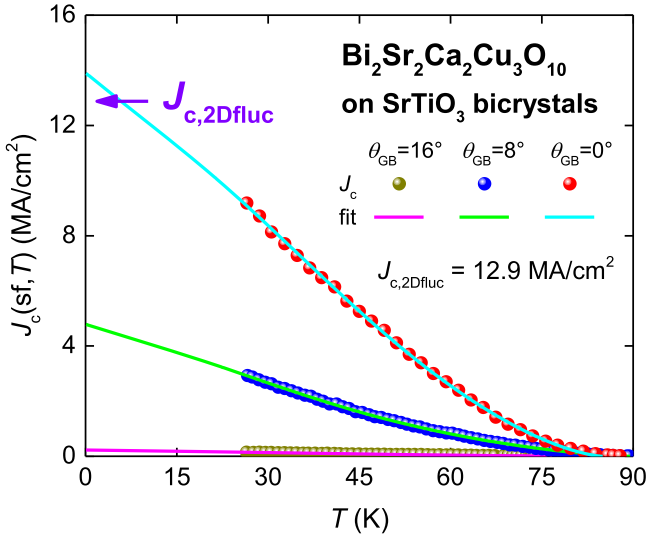

Figure 6. Experimental J_c(sf, T, θ_{GB}) data and data fit to BCS-based model [5] for $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$ film deposited on STO [001]-tilted bicrystals [30].

Zhang *et al* [27] are free of weak-links and the critical current is reaching full capacity in these films.

We now consider the case of a single layer FeSe film with $T_c = 99$ K [26]. By substituting the relevant parameters into equation (8) we obtain $J_{c,2Dfluc}$(sf, $T \simeq 0$ K) = 15.1 MA cm^{-2}. Experimental J_c(sf, T) data for this film has been reported by Ge *et al* [26] and it is shown in figure 5 together with the calculated $J_{c,2Dfluc}$(sf, $T \sim 0$ K). It can be seen that this state-of-art FeSe film is slightly affected by weak-links as the ratio J_c(sf, $T = 4$ K)/$J_{c,2Dfluc}$(sf, $T \sim 0$ K) = 0.86 is less than 1. Taking into account that J_c(sf, T) has an upturn in shape at low temperature, we expect the ratio J_c(sf, T)/$J_{c,2Dfluc}$(sf, $T \sim 0$ K) for $T < 4$ K will increase.

3.2. Cuprates

The cuprates are another class of quasi-2D superconductors and here we will show the application of our criterion for two commonly studied compounds, $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$ and $YBa_2Cu_3O_{7-\delta}$.

3.2.1. $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$. Hänisch *et al* [30] have measured the J_c(sf, T) of high-quality $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$ thin films deposited on [001] tilted $SrTiO_3$ bicrystals with a misorientation angle of $\theta_{GB} = 0°$, 8°, 16°, 24°, 26°, 30°, and 36.8°. The crystalline structure of the $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$ phase has been reported on elsewhere [31], and the value $d_{001} = 0.59$ nm can be found in [7].

The model reported in [5] was used to fit the J_c(sf, T) experimental data [30] to deduce T_c and obtain an extrapolated value for J_c(sf, $T \sim 0$ K). To perform this fit we used $\kappa = 170$ [4]. The result of the fit is shown in figure 6 where a value of $T_c = 86 \pm 1$ K was deduced. Substituting the values into equation (8) gives $J_{c,2Dfluc}$(sf, $T \simeq 0$ K) = 12.9 MA cm^{-2}. Our fit of the J_c(sf, T) experimental data to model [5] gives an extrapolated value of J_c(sf, $T \simeq 0$ K) = 13.9 MA cm^{-2} which is in excellent agreement with the expectation that a high-quality

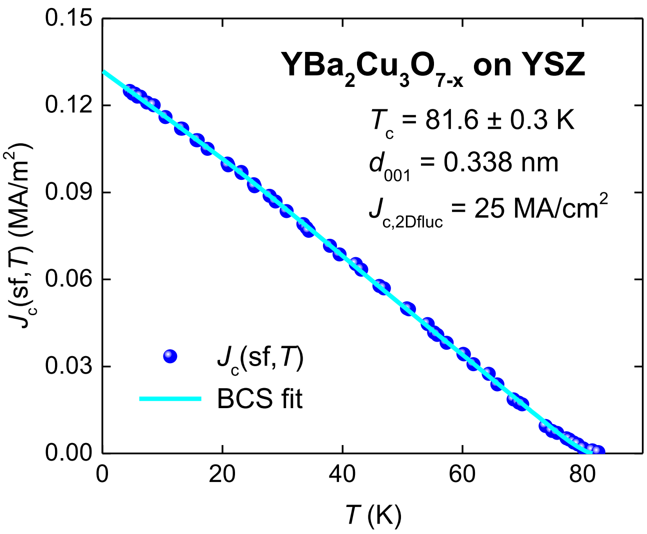

Figure 7. Experimental J_c(sf, T) data and data fit to our model [5] for a $YBa_2Cu_3O_7$ film deposited on YSZ reported by Widder *et al* [3]. The $J_{c,2Dfluc}$(sf, $T \sim 0$ K) value is not shown on the graph but stated in the figure.

$Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$ film deposited on a single crystal should be free of weak-links.

It can also be seen in figure 6 that J_c(sf, T) for samples deposited on a STO bicrystal with $\theta_{GB} = 8°$ is almost three times lower than $J_{c,2Dfluc}$(sf, $T \sim 0$ K).

3.2.2. $YBa_2Cu_3O_7$. The influence of grain boundaries on critical currents in $YBa_2Cu_3O_7$ has been extensively studied for decades [32–35]. Here we only demonstrate the remarkable progress in manufacturing commercial $REBa_2Cu_3O_7$ superconducting wires over the last two decades.

$YBa_2Cu_3O_7$ has a distance between CuO_2 planes of $d_{001} = 0.338$ nm [36] and a Ginzburg–Landau parameter of $\kappa = 95$ [4].

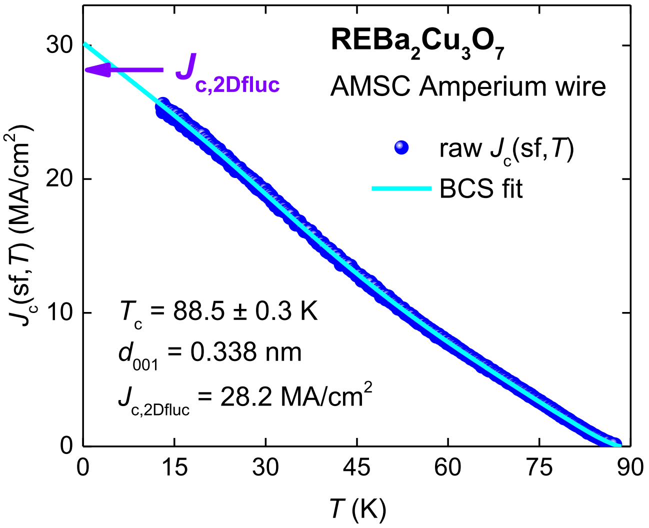

Figure 8. Experimental J_c(sf, T) data for AMCS Amperium wire [11] data with to our model [5].

In figure 7 we show the result of early work on 2G wire development reported by Widder *et al* [3] together with a fit of the data to our model [5]. The $YBa_2Cu_3O_7$ film was deposited on a polished Y_2O_3-stabilized ZrO_2 substrate (YSZ). The transition temperature was deduced to be $T_c = 81.6 \pm 0.3$ K and an evaluation of equation (8) gives $J_{c,2Dfluc}(\mathrm{sf}, T \simeq 0\ \mathrm{K}) = 25.0$ MA cm^{-2}.

It is obvious that the experimental $J_c(\mathrm{sf}, T \sim 0\ \mathrm{K})$ is more than two orders of magnitude below $J_{c,2Dfluc}(\mathrm{sf}, T \sim 0\ \mathrm{K})$ (figure 7). Widder *et al* [3] showed in their figure 3 that the $YBa_2Cu_3O_7$ film has a granular structure and the film was strongly affected by weak-links.

In figure 8 we show experimental J_c(sf, T) data for a commercial $REBa_2Cu_3O_7$ wire manufactured by AMCS [11] with a fit to our model [5]. We measured the J_c(sf, T) data on a recently developed 1 kA-class cryogen-free critical current characterization system [37].

It can be seen for this wire, having a transition temperature of $T_c = 88.5$ K, that the extrapolated J_c(sf, T) value at $T \sim 0$ K is more than 30 MA cm^{-2} which is above the weak-link limit of

$$J_{c,2Dfluc}(\mathrm{sf}, T \simeq 0\ \mathrm{K}) = 28.2\ \mathrm{MA\ cm^{-2}}. \quad (9)$$

4. Summary

In conclusion, we have proposed a simple criterion to determine the presence or absence of weak-links in layered quasi-2D superconductors, which was applied to iron-based and cuprate superconductors. To calculate the limit only the Ginzburg–Landau parameter, transition temperature and 2D layers separation distance are needed. This approach might be considered as additional useful tool to optimize R&D efforts in developing practical HTS wires.

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