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Anisotropic in-plane reversible strain effect in $Y_{0.5}Gd_{0.5}Ba_2Cu_3O_7-\delta$ coated conductors*

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Abstract
Recent experiments have shown that reversible effects of strain on the critical current density and flux pinning strength in the high-temperature superconductor Bi$_2$Sr$_2$CaCu$_2$O$_x$ can be explained entirely by the pressure dependence of its critical temperature. Such a correlation is less simple for RE–Ba$_2$Cu$_3$O$_{7-\delta}$ (RE = rare earth) superconductors, in part because the in-plane pressure dependence of its critical temperature is highly anisotropic. Here, we make a qualitative correlation between the uniaxial pressure dependence of the critical temperature and the reversible strain effect on the critical current of RE–Ba$_2$Cu$_3$O$_{7-\delta}$ coated conductors by taking the crystallography and texture of the superconducting film into account. The strain sensitivity of the critical current is highest when strain is oriented along the [100] and [010] directions of the superconducting film, whereas the critical current becomes almost independent of strain when strain is oriented along the [110] direction. The results confirm the important role of the anisotropic pressure dependence of the critical temperature on the reversible strain behavior of RE–Ba$_2$Cu$_3$O$_{7-\delta}$. The reversible strain effect in RE–Ba$_2$Cu$_3$O$_{7-\delta}$ is expected to decrease the performance of the conductor in many applications, such as high-field magnets, but the effect may be only minor in coated conductor cables, where strain is generally not aligned with the tape axis.

1. Introduction
Axial strain irreversibly degrades the critical current ($I_c$) of high-temperature superconducting tapes and wires when it exceeds the irreversible strain limit and the conductor is damaged mechanically [1–4]. Strain affects the critical current density ($J_c$) and flux pinning strength of Bi$_2$Sr$_2$CaCu$_2$O$_x$ (Bi-2212) wires and tapes [5], Bi$_2$Sr$_2$CaCu$_2$O$_x$ (Bi-2223) tapes [6–9], and RE–Ba$_2$Cu$_3$O$_{7-\delta}$ (RE = Y, Gd, Dy, Sm, etc) (REBCO) coated conductors [10–17], even before damage to the superconductor occurs. This change is fully reversible, which means that $I_c$ and the flux pinning strength return to their initial value after the strain has been released. Recent work rules out that the reversible strain effect originates from grain boundaries where dislocations may obstruct the grain boundary supercurrent [18, 19]. Instead, in the case of Bi-2223 tapes, the linear change in $I_c$ with strain and the strain dependence of the flux pinning force can be entirely explained by the pressure dependence of the critical temperature ($T_c$) [9]. Although the strain dependence of $I_c$ in most REBCO coated conductors is approximately parabolic, it is linear in coated conductors that are fabricated with the inclined-substrate deposition (ISD) method. Similar to Bi-2223, the linear, reversible strain dependence of both $I_c$ and $T_c$ suggests a correlation between the two for ISD REBCO coated conductors [20, 21].

A closer investigation into the microstructure of REBCO coated conductors is needed to fully correlate the uniaxial

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The effect of strain on the critical current was measured on several types of REBCO coated conductors (see table 1). Samples S-1, S-2 and S-3 were GdBa$_2$Cu$_3$O$_{7-δ}$ (GBCO), YBa$_2$Cu$_3$O$_{7-δ}$ (YBCO) and Y$_0.5$Gd$_{0.5}$Ba$_2$Cu$_3$O$_{7-δ}$ (YGBCO) coated conductors, respectively deposited on a 50 μm thick Hastelloy C-276 substrate using an ion-beam-assisted deposition (IBAD) template. The 1 μm thick REBCO superconducting layer was deposited on top of the buffer layers by metal–organic chemical-vapor deposition (MOCVD) [26, 27]. Such a deposition route results in a twinned superconducting film that is oriented with the [100] and [010] directions along the tape axis [28]. A silver cap layer, 2–3 μm thick, was deposited on top of the superconducting layer. Some of the coated conductors were slit from a 12 mm wide tape to their final width of 4 mm, and all samples were surround-plated with 20 μm of copper for electrical and thermal stability.

Sample S-4 was a 1 μm thick DyBa$_2$Cu$_3$O$_{7-δ}$ (DBCO) film that was deposited on an ISD MgO template [29]. A silver cap layer, 10 μm thick, was deposited on top of the superconducting layer. The twinned superconducting film that was deposited on the ISD template is aligned with the [110] direction along the tape axis [30], which makes a distinct contrast to the MOCVD conductors in which the [100] or [010] direction tends to be aligned along the tape axis.

Superconducting bridges were prepared from sample S-3 by cutting sections 12 mm long and 5 mm wide from the 12 mm wide conductor at specific angles with respect to the conductor axis. Wet chemical etching was used to remove most of the copper, except in locations where current and voltage contacts needed to be soldered. The contact pad areas were manually painted with GE-7031 varnish and the copper layer was etched with a solution of 15–20% ammonium persulfate and 75–80% water for 25–30 min at room temperature. Part of the silver cap layer was removed by etching with a solution of ammonia water and hydrogen peroxide. A single bridge, 1 mm in length and 200 μm in width, was automatically patterned through the silver and superconducting layers with a Nd–YAG laser on each of the cut pieces (see figure 1). A total of 12 bridges (samples B-1 to B-12; see table 2 below) were patterned at specific angles α, with respect to the axis of the original tape, ranging from 0° (parallel to the tape axis) to 90° (perpendicular to the tape axis). The orientation of the bridge was measured after patterning with an uncertainty in α of about ±0.5°. The critical current density of the laser patterned bridges was within 75% of that of the original 12 mm wide conductor.

The coated conductors used to pattern the bridges contain local defects that predominantly run along the length of the

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**Table 1.** Properties of REBCO samples.

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Superconducting film</th>
<th>Template</th>
<th>Tape width (mm)</th>
<th>$J_c$ (MA cm$^{-2}$) 76 K, self-field</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-1</td>
<td>GdBa$_2$Cu$<em>3$O$</em>{7-δ}$</td>
<td>IBAD-MOCVD</td>
<td>4</td>
<td>2.5</td>
</tr>
<tr>
<td>S-2</td>
<td>YBa$_2$Cu$<em>3$O$</em>{7-δ}$</td>
<td>IBAD-MOCVD</td>
<td>4</td>
<td>3.0</td>
</tr>
<tr>
<td>S-3</td>
<td>Gd$<em>{0.5}$Y$</em>{0.5}$Ba$_2$Cu$<em>3$O$</em>{7-δ}$</td>
<td>IBAD-MOCVD</td>
<td>12</td>
<td>2.5</td>
</tr>
<tr>
<td>S-4</td>
<td>DyBa$_2$Cu$<em>3$O$</em>{7-δ}$</td>
<td>ISD</td>
<td>4</td>
<td>1.8</td>
</tr>
</tbody>
</table>

---

**Table 2.** Parameter values used in equation (1).

<table>
<thead>
<tr>
<th>Sample #</th>
<th>α (deg)</th>
<th>$I_c$ ($\varepsilon_m$) (A)</th>
<th>$\varepsilon_m$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-1</td>
<td>0</td>
<td>97.4</td>
<td>4667</td>
</tr>
<tr>
<td>S-2</td>
<td>0</td>
<td>137.3</td>
<td>9378</td>
</tr>
<tr>
<td>S-3</td>
<td>1.1</td>
<td>4.91</td>
<td>7705</td>
</tr>
<tr>
<td>S-4</td>
<td>1.0</td>
<td>4.98</td>
<td>7647</td>
</tr>
<tr>
<td>B-1</td>
<td>22.7</td>
<td>3.25</td>
<td>4783</td>
</tr>
<tr>
<td>B-2</td>
<td>21.9</td>
<td>4.70</td>
<td>4744</td>
</tr>
<tr>
<td>B-3</td>
<td>44.7</td>
<td>5.13</td>
<td>259</td>
</tr>
<tr>
<td>B-4</td>
<td>47.4</td>
<td>5.26</td>
<td>580</td>
</tr>
<tr>
<td>B-5</td>
<td>65.1</td>
<td>5.18</td>
<td>4045</td>
</tr>
<tr>
<td>B-6</td>
<td>67.5</td>
<td>0.57</td>
<td>—</td>
</tr>
<tr>
<td>B-7</td>
<td>69.8</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>B-8</td>
<td>89.0</td>
<td>4.92</td>
<td>7745</td>
</tr>
<tr>
<td>B-9</td>
<td>88.2</td>
<td>4.54</td>
<td>8866</td>
</tr>
<tr>
<td>B-10</td>
<td>88.3</td>
<td>0.73</td>
<td>—</td>
</tr>
</tbody>
</table>

---

Figure 1. Optical image of one of the bridges that was patterned by laser in sample S-3. The bridge is 1 mm long and 200 μm wide. The remaining copper on the pads where the voltage contacts was soldered is visible in the top part of the image. The black lines are the laser cuts. The arrows show how the alignment of the bridge with the a- and b-axes of the twinned superconducting film defines the angle α. The inset at the lower left corner shows the entire sample, including the copper contact pads. The scale bar on the left is 300 μm.

(This figure is in colour only in the electronic version)
3. Results and discussion

3.1. Reversible effect of strain on $I_c$ in REBCO coated conductors

Typical dependences of the critical current of REBCO coated conductors on strain are presented in figure 3. The normalized $I_c$ for GdBa$_2$Cu$_3$O$_{7-δ}$ sample S-1 is only about 57% of that of YBa$_2$Cu$_3$O$_{7-δ}$ sample S-2 (see table 2). The superconducting film is under the optimum strain state at a strain $\varepsilon_m$ at which the peak in $I_c$ is reached. The critical currents, as shown in figure 3, are normalized to their peak values for IBAD-MOCVD samples S-1 and S-2, while $I_c$ of the ISD sample S-4 is normalized to its value at zero strain. The intrinsic strain of the ISD sample S-4 is unknown, because the optimum strain state cannot be determined from its linear strain dependence. The critical current of sample S-4 is therefore plotted as a function of applied strain. The change in $I_c$ with strain is fully reversible in all three samples over the range of strain shown, which was confirmed by a full recovery of $I_c$ after the strain has been released (not shown).

The power-law strain dependence of the critical current in IBAD-MOCVD conductors is often described with the following fitting function [15–17]:

$$I_c(\varepsilon, \alpha) = I_c(\varepsilon_m)(1 - a(\alpha)\varepsilon - \varepsilon_m(\alpha))^2,$$

where the parameter $a$ represents the strain sensitivity of $I_c$ and $I_c(\varepsilon_m)$ is the maximum critical current at an applied strain $\varepsilon_m$.

The expansion of equation (1) by adding the angular dependence, with $\alpha$ defined as the angle between the strain and the $a$- and $b$-axes of the superconducting film, will be discussed below. The main difference between the two IBAD-MOCVD samples (S-1 and S-2) is that the strain sensitivity of $I_c$ for GdBa$_2$Cu$_3$O$_{7-δ}$ sample S-1 is only about 57% of that of YBa$_2$Cu$_3$O$_{7-δ}$ sample S-2 (see table 2) [37]. Such a large difference in strain sensitivity could be caused by differences between GdBa$_2$Cu$_3$O$_{7-δ}$ and YBa$_2$Cu$_3$O$_{7-δ}$ in the uniaxial pressure dependences of $T_c$, but also by differences in microstructure, as will be discussed in section 3.2.
3.2. Influence of the crystallographic texture on the reversible strain effect

The pressure dependence of $T_c$ in Bi-2212 and Bi-2223 is fully isotropic within the $ab$-plane: $T_c$ increases linearly with pressure applied along the $a$- and $b$-axes at the same rate $[23–25]$. Because of this isotropic in-plane pressure dependence, and the fact that a macroscopic transport current runs predominantly within the $ab$-planes, microstructural features, such as grain boundaries and grain orientation, do not influence the reversible strain effect on $I_c$ and on the flux pinning strength measured in Bi-2223 tapes. Although $T_c$ most likely varies locally within the microstructure, its relative change with in-plane strain is the same throughout the microstructure, and thus a quantitative correlation between the reversible strain effect and the pressure dependence of $T_c$ in Bi-2223 tapes could be made $[9]$. The change in $T_c$ with pressure is measured when $I_c(0, \varepsilon)$, the steepness of the superconducting transition, is assumed to be the same for each grain on either side of each twin plane, and $I_c(0, \varepsilon)$ needs to be taken into account to make a direct correlation between the pressure dependence of $T_c$ and the reversible strain effect and the pressure dependence of $T_c$ in REBCO coated conductors.

On the other hand, the superconducting microstructure needs to be taken into account to make a direct correlation between the pressure dependence of $T_c$ and the macroscopic reversible strain effect on $I_c$ in REBCO coated conductors. The macroscopic transport current over the two domains outlined in figure 4(a) is given by $I_c(T, \varepsilon) \propto V_1(\varepsilon) + V_2(\varepsilon)$, where $V_1$ and $V_2$ are the voltages generated across domains 1 and 2 on either side of the twin plane that depend on the strain and temperature-dependent critical currents $I_c(\varepsilon, T)$ and $I_c(\varepsilon, T)$ of both domains in series, as defined by equation (4). (b) Representation of two domains of 90° rotation across a twin boundary in an ISD DBCO coated conductor with the strain applied along the [110] direction of the superconducting film.

Figure 4. (a) Representation of two domains of 90° rotation across a twin boundary in an IBAD-MOCVD REBCO coated conductor. The twin boundaries are oriented at 45° to the $a$- and $b$-axes of the superconducting film. The linear change in $T_c$ and $J_c$ with strain that is applied along the conductor axis is indicated on each side of the twin boundary, together with the strain dependence of $I_c$ of both domains in series, as defined by equation (4). (b) Representation of two domains of 90° rotation across a twin boundary in an ISD DBCO coated conductor with the strain applied along the [110] direction of the superconducting film.

with the temperature dependence of the critical current of each domain given by $[40]$:

$$I_{c,1}(T, \varepsilon_0) = I_{c,1}(0, 0) \left(1 - \frac{T}{T_{c,1}(\varepsilon_0)}\right)^{1.5} = I_{c,1}(0, 0) \left(1 - \frac{75.9}{-b\varepsilon_0 + T_{c}(0)}\right)^{1.5}$$

(2b)

and

$$I_{c,2}(T, \varepsilon_0) = I_{c,2}(0, 0) \left(1 - \frac{T}{T_{c,2}(\varepsilon_0)}\right)^{1.5} = I_{c,2}(0, 0) \left(1 - \frac{75.9}{b\varepsilon_0 + T_{c}(0)}\right)^{1.5}.$$  

(2c)

Here, $V_1$ and $V_2$ are the voltages generated across domains 1 and 2 on either side of the twin plane that depend on the strain and temperature-dependent critical currents $I_{c,1}(\varepsilon, T)$ and $I_{c,2}(\varepsilon, T)$. The strain dependence of $I_c$ across the twin plane is caused entirely by the change in $T_c$ with strain at the rate indicated by parameter $b$, which is expected to be around 4 K/%, based on the in-plane elastic modulus of 189 GPa for YBCO $[41]$. The $n$-value, which determines the steepness of the superconducting transition, is assumed to be the same for each grain on either side of each twin plane, and $I_{c,1}(0, 0) = I_{c,2}(0, 0)$. Also, when both domains on either side of the twin plane are equal in size, the voltage at the criterion that determines $I_c$ is: $V_{c,\text{tot}} = 2V_{c,1} = 2V_{c,2}$. With these
Nevertheless, a key characteristic of such conductors is the strain dependence of the overall critical current $I_c$ that is measured with respect to the conductor axis, parallel to the [110] direction of the superconducting film. Several bridges were patterned by laser in sections cut from IBAD-MOCVD sample S-3 to determine the existence of such an anisotropic in-plane reversible strain effect. The orientation of each bridge with respect to the axis of the coated conductor varies between 0° and 90° (see table 2), whereas the strain was always applied along the direction of the bridge.

Because of twinning, the superconducting lattice in IBAD-MOCVD REBCO coated conductors alternates the [100] and [010] directions along the length and across the width of the conductor. A similar strain dependence of $I_c$ for bridges that are patterned at a nominal angle of 0° from the conductor axis (samples B-1 and B-2), and patterned at a nominal angle of 90° with respect to the conductor axis (samples B-10 to B-12), is expected. Such a comparable strain dependence of $I_c$ is indeed measured, as is shown in figure 5(a), where the normalized critical currents for samples B-1 and B-10 are plotted as a function of applied strain. The strain dependence of $I_c$ is fitted with equation (1), and the fitting parameters are listed in table 2. Unfortunately, only data for the bridges that were patterned at a nominal angle of 0° could be measured as a function of compressive strain, since the contact pads of samples B-1 and B-2 delaminated during the measurement. The change in $I_c$ with strain is comparable for both samples and was fully reversible, which was confirmed by unloading the strain (open symbols). The strain dependence of the normalized $I_c$ of bridges B-3 and B-7, that are oriented at an angle of 22.7° and 65.1° with respect to the conductor axis, is shown in figure 5(b). The strain sensitivity of $I_c$ in these two samples is reduced by about 46% and 54%, respectively, compared to that of the sample with the highest strain sensitivity (B-11; see table 2), in which strain was oriented along the $a$- and $b$-axes.

The critical current of the bridges that were patterned at a nominal angle of 45° with respect to the conductor axis, along the [110] direction of the superconducting film, is almost independent of strain (see figure 5(c)). The strain sensitivity of $I_c$ for samples B-5 and B-6, patterned at 44.7° and 47.4°, respectively, is only about 3% and 7% of that for sample B-11. The fact that $I_c$ is still slightly dependent on strain is likely explained by taking its crystallographic texture into account. The superconducting grains in ISD DBCO coated conductors (and others, such as ISD YBCO [42]) are aligned with their [110] direction parallel to the conductor axis [30]. Strain that is applied along the conductor axis will thus be oriented at a 45° angle with both the $a$- and $b$-axes (see figure 4(b)). The change in $T_c$ with the deformation along the $a$-axis will be largely canceled by the opposite sign change in $T_c$ with the deformation along the $b$-axis, and $I_c$ will be almost insensitive to axial strain, independent of the presence of twin planes.
Figure 5. (a) Strain dependence of $I_c$ at 76 K, normalized to its value at zero applied strain, of samples B-1 and B-10 that are oriented at 1.1° and 89.0° with the conductor axis, respectively. (b) Strain dependence of the normalized $I_c$ of samples B-3 and B-7 that are oriented at 22.7° and 65.3° with the conductor axis, respectively. (c) Strain dependence of the normalized $I_c$ of samples B-5 and B-6 that are oriented at 44.7° and 47.4° with the conductor axis, close to being parallel to the [110] direction of the superconducting film. The error bars indicate the ±0.3% uncertainty in $I_c$. All data were reversible, which was confirmed by unloading the strain (open symbols). The solid lines represent a fit to the data with equation (1).

Figure 6. (a) Normalized $I_c$ as a function of intrinsic strain $\varepsilon_0$ of samples B-3 and B-10 and as a function of applied strain for sample B-6 at 76 K, highlighting the change in strain sensitivity with in-plane strain orientation. The solid lines are a fit to the data with equation (1). (b) Comparison between the strain dependence of the normalized $I_c$ of IBAD-MOCVD sample B-6 and ISD sample S-4 at 76 K.

caused by the small but finite in-plane grain misalignment in the coated conductor, and by the ±2.5° uncertainty in the alignment between the applied strain and the [110] direction of the film. The strain ($\varepsilon_m$) at which the peak in $I_c$ occurs is $-0.67%$ for sample B-5 and $-0.39%$ for sample B-6, which is at a much higher compressive strain than that of the other bridges, where $\varepsilon_m$ is between 0.02% and 0.1%. It is likely that $\varepsilon_m$ is determined by other factors beside the initial strain state of the superconducting film, which is a conclusion similar to that drawn when investigating the reversible strain effect as a function of temperature and in the presence of a magnetic field [17, 43]. Finally, the strain dependence of the normalized critical current of sample B-10 (89.0°), sample B-3 (22.7°) and sample B-5 (44.7°) are compared in figure 6(a) to clearly demonstrate the highly anisotropic nature of the in-plane reversible strain effect in IBAD-MOCVD coated conductors.

Differences in strain sensitivity of $I_c$ exist between the IBAD-MOCVD bridges and the ISD coated conductor when,
in both cases, strain is applied along the [110] direction of the superconducting film. The small strain dependence of $I_c$ that remains in IBAD-MOCVD sample B-6 is much lower than the strain sensitivity of $I_c$ for ISD sample S-4 (see figure 6(b)). The higher, linear strain sensitivity of $I_c$ measured in ISD DBCO sample S-4 is likely caused by its much broader in-plane grain misorientation, besides a possible difference in pressure dependence of $T_c$ in DBCO, compared to YGBCO. For instance, the $c$-axis in MOCVD IBAD YGBCO is oriented normal to the substrate, while the $c$-axis in ISD DBCO is tilted sideways by a relatively large angle [44]. A fully three-dimensional strain investigation has to be performed for us to fully understand the differences between the strain dependences of $I_c$ in the two types of coated conductors.

The anisotropic nature of the pressure dependence of $T_c$ in REBCO causes the strain sensitivity of $I_c$ to depend on the in-plane strain orientation. The strain sensitivity parameter $a(\alpha)$ of the patterned bridges is proportional to the change in $T_c$ with strain, since differences in microstructure between bridges patterned from the same section of coated conductor are expected to be negligible:

$$a(\alpha) \approx \frac{dT_c}{d\varepsilon} = \varepsilon \cos(\alpha) \frac{dT_c}{d\varepsilon_a} + \varepsilon \sin(\alpha) \frac{dT_c}{d\varepsilon_b} \quad (5a)$$

The strain component parallel to the $a$-axis is defined as $\varepsilon_a$ and the component parallel to the $b$-axis is defined as $\varepsilon_b$. The small change in $T_c$ with strain along the $c$-axis is neglected in this approximation, because the strain is applied within the $ab$-plane. Since $dT_c/d\varepsilon_a$ and $dT_c/d\varepsilon_b$ in REBCO are equal, but of opposite sign [22], equation (5a) can be simplified to

$$a(\alpha) = a(0^\circ) \cos(\alpha) - \sin(\alpha) \quad (0^\circ \leq \alpha \leq 90^\circ). \quad (5b)$$

Parameter $a(0^\circ)(=a(90^\circ))$ is the maximum strain sensitivity that occurs when the applied strain is oriented parallel to the [100] and [010] directions of the superconducting film. The expected angular dependence of $a(\alpha)$, according to equation (5b), with $a(0^\circ) = 7985$ as the average value of $a$ for samples B-1, B-2, B-10 and B-11, is plotted in figure 7. The strain sensitivity of $I_c$ for each bridge obtained from experiments is included in the figure. A good agreement between the model and data is obtained, except for sample B-11. The strain sensitivity of $I_c$ of samples B-1, B-2 (at 1.1° and 1.0°, respectively) and B-10 (at 89.0°) is between 7647 and 7744, while that of sample B-11 (at 88.2°) is much higher at 8866 (see table 2). This relatively large difference can be explained by a small defect in the bridge of sample B-11, which was observed with magneto-optical imaging (see figure 5(a)). Stress concentrations around this defect likely cause a higher strain sensitivity of $I_c$, although the defect is small enough not to reduce the overall $I_c$ of the bridge.

An anisotropic in-plane reversible strain effect is highly likely to be present in other types of coated conductors besides IBAD-MOCVD. The strain dependence of $I_c$ in ISD DBCO is expected to become a power-law function when strain is applied at 45° to the tape axis along the [100] and [010] directions of the DBCO film. The power-law dependence could potentially be asymmetric with respect to its peak, due to the relatively high slope of the linear $I_c$ versus strain dependence when strain is aligned with [110]. Also, a power-law, reversible strain dependence of $I_c$ similar to that in IBAD-MOCVD coated conductors has been measured in coated conductors prepared by metal–organic deposition (MOD) on rolling assisted biaxially textured substrates (RABiTS), and those prepared by pulsed-laser deposition (PLD) on IBAD substrates [19, 45, 46]. A strain independent-$I_c$ is expected in these conductors when the strain is applied along the [110] direction of the superconducting film.

The anisotropic in-plane reversible strain effect in IBAD-MOCVD coated conductors reported here has significant implications for REBCO coated conductors. For instance, the critical current of IBAD-MOCVD coated conductors that are wound into compact cables is determined mainly by the strain component along the axis of the conductor, and not by the maximum strain component [47]. In some cable configurations, the critical current remained almost unchanged, even though the conductors experienced a significant compressive strain [37]. Since the strain applied to the IBAD-MOCVD coated conductor in this particular cable configuration turns out to be oriented close to 45° from the conductor axis, the principal strain then lies along the [110] direction of the superconducting film. Cables wound from ISD DBCO coated conductors in this particular cable configuration would thus be expected to show a much larger reversible degradation in $I_c$ due to cabling, since the resulting cabling strain occurs at 45° to the conductor axis and is thus oriented along the [100] and [010] directions of the superconducting film. This hitherto unknown strain effect in coated conductors thus has an important and, for modern IBAD-MOCVD conductors, a very positive effect on twisted cables.
4. Conclusions

For the first time, we have established a qualitative correlation between the uniaxial pressure dependence of the critical temperature and the reversible strain effect on the critical current in high-temperature superconducting REBCO coated conductors. An anisotropic in-plane reversible strain effect on the critical current in IBAD-MOCVD REBCO coated conductors was discovered. The maximum strain sensitivity of the critical current occurs when the applied strain is aligned with the [100] and [010] directions of the superconducting film, and the critical current becomes almost insensitive to strain when the strain is aligned with the [110] direction. This effect has been directly correlated to the uniaxial pressure dependence of the critical temperature, which is highly anisotropic in REBCO superconductors. The effect has important implications for the application of coated conductors, especially in compact cables.

Acknowledgments

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