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Improved Pinning in RE-123 Films for Coated Conductors

In this contribution we report on the improvement of pinning and critical current density in High Temperature Superconductor (HTSC) films that can be used for Coated Conductors, the 2nd generation of HTSC tapes. Pure and mixed $REBa_2Cu_3O_x$ (RE : Gd, Eu, Nd) films and heterostructures were prepared by Pulsed Laser Deposition (PLD) and investigated regarding their current carrying capabilities. A strong improvement in the critical current density and an increased irreversibility field was observed for the mixed RE123 films. This improvement is due to stress fields introduced into the lattice by statistical arrangement of the differently sized RE-ions. In multilayer heterostructures, these effects have also significant implications on the anisotropy of J_c in the presence of magnetic fields.

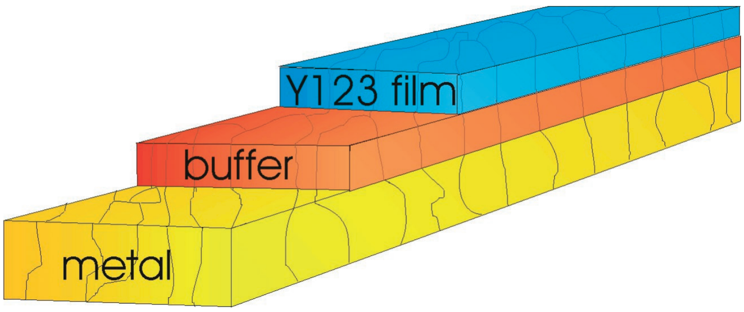

Fig. 1: Schematic illustration of the Coated Conductor architecture

The development of High-Temperature Superconductor (HTSC) power applications like motors, transformers or cables require a high current carrying and low cost basic conductor that can be used in magnetic fields. Currently HTSC coated conductors (CC) are under development as a very promising 2nd generation HTSC tape that is able to fulfil all the necessary requirements. The CC approach is based on depositing epitaxially a HTSC film onto a highly biaxially textured buffered metal tape (Fig. 1). A very sharp biaxial texture is required since already low-angle grain boundaries reduce significantly the overall critical current density. Very good textures, and therefore also nearly single crystalline J_c-values exceeding 10^6 A/cm^2 at 77 K and in zero field, can be obtained on Ni-5at%W metal tapes with a sharp cube texture due to recrystallization after heavy cold rolling [1,2]. During the last years, J_c was mainly improved by sharpening the substrate texture. Our recent investigations, however, demonstrated that for such low-angle grain boundary networks the critical current in magnetic fields is limited by the intrinsic grain properties of the HTSC films and not any more by the low-angle grain boundaries [3]. Since the main application sector of these tapes will be connected with magnetic fields, further improvements of the intrinsic HTSC pinning properties in films used for CCs are required. Based on former investigations in Y123 bulk material [4] we found last year a very promising approach to improve J_c by using mixed $REBa_2Cu_3O_x$ (RE : Gd, Eu, Nd) films (GEN123) compared to pure RE123 films [5,6]. In our experiments all films were deposited by off-axis pulsed laser deposition (PLD) to avoid as much as possible any other growth defects that influence the pinning properties. We found no obvious microstructural differences (like island size and density) between GEN123 and the corresponding pure RE123 thin films. Standard four-probe transport measurements were performed using a Quantum Design PPMS system at temperatures down to 4 K and in magnetic fields of up to 9 T. The resulting irreversibility line (IRL), defined by zero resistance at various given magnetic fields, is shown in Fig. 2. It is obvious that the IRL for GEN123 films has shifted toward the region of higher temperature and field, both for magnetic field directions H∥c and H⊥c where intrinsic pinning occurs. The improved irreversibility behaviour

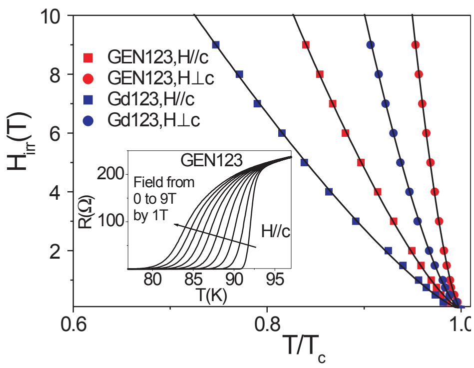

Fig. 2: IRL determined by zero resistance and its good fitting by $H_{irr} \sim (1-T/T_c)^\beta$ (see solid lines in main plot). Inset shows that resistance broadens with magnetic field.

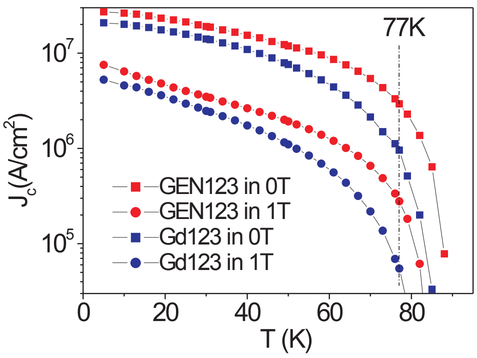

Fig. 3: Temperature dependence of J_c for H= 0, and 1T (H//c). The J_c in GEN123 is improved in comparison with Gd123. The dash lines are guides to the eye.

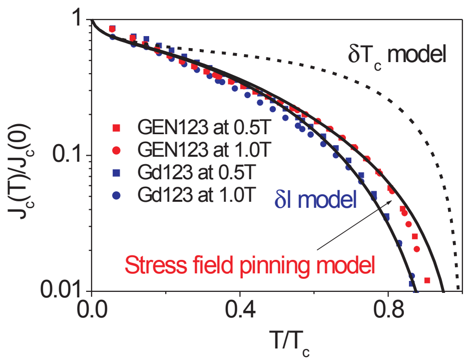

Fig. 4: Fitting of normalized $J_c(T)$ with various pinning models.

implies the enhancement of flux pinning and thus an increase in J_c. Indeed, it is found that J_c in rare earth mixed samples is pronouncedly higher than in our off-axis deposited RE123 films as shown in Fig. 3. A detailed J_c-analysis in the presence of magnetic fields reveals an unchanged accommodation field in the GEN films so that the improved pinning is not due to the presence of linear or columnar defects but can be rather attributed to uncorrelated point like defects. To identify the origin of these uncorrelated pinning centres, the temperature dependence of the critical current density of pure Gd123 and mixed GEN123 films was analysed using different pinning models like the δl-, δT_c- and a modified stress field model as shown in Fig. 4. The normalized $J_c(T)$ for GEN123 is well fitted over the main temperature range with the stress field pinning model, while Gd123 films agree well with the model of δl, indicating that the randomly distributed stress fields caused by the differently sized RE ions in mixed GEN123 films are the main pinning centres responsible for the significant J_c-improvements. When the temperature approaches the irreversibility temperature, the increased thermally activated flux flow requires stronger pinning, hence, the stress field is no longer dominating. These basic investigations were transferred to the CC technology. First deposition experiments of mixed RE123 films using biaxially textured Ni tapes as substrates reveal also an increased critical current density over a broad magnetic field range. To study the effects of epitaxial strain and stress on flux pinning, further experiments with RE123 multilayers were performed [7]. A Trilayer (TL) film consisting of 42 nm layers of Gd123, Nd123 and Eu123 in sequence was compared to a superlattice film (SL) of same thickness, consisting of 5 periods of trilayers, each trilayer being 8.3 nm of Gd123, Nd123, and Eu123 in sequence (see Fig. 5a) . Angle dependent J_c measurements show an enhanced anisotropy in the SL film. The angular dependence of the flux-pinning

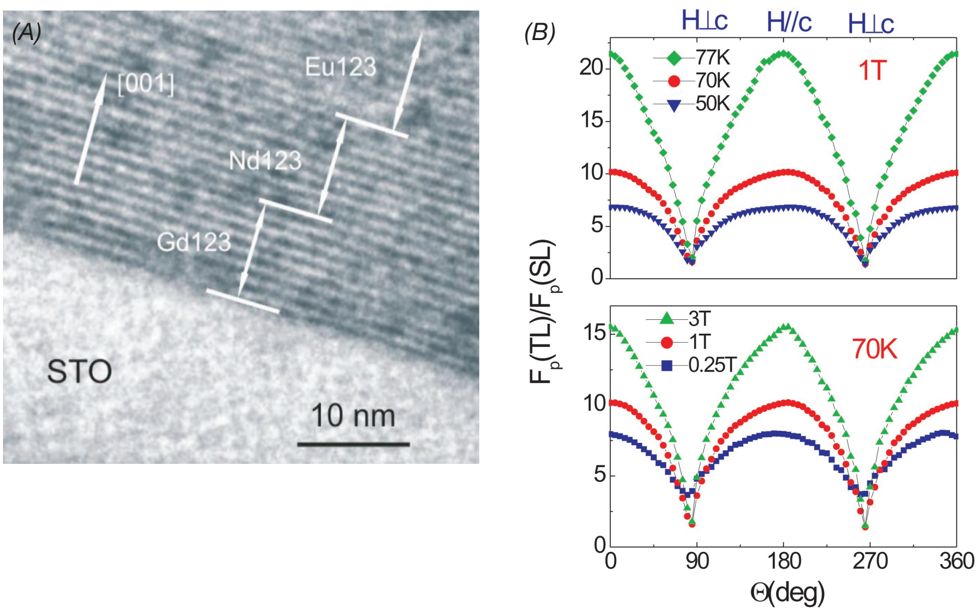

Fig. 5: (A) A cross-sectional TEM image of superlattice sample, showing layer by layer growth without either highly defected interfaces or intergrowth. (B) Angular dependence of flux pinning improvement characterised by flux pinning force density ratio $F_p(TL)/F_p(SL)$, showing flux pinning most variable at H//c.

force ratio $F_p(TL)/F_p(SL)$ (Fig. 5b) implies no pronounced difference in the flux pinning of intrinsic layer structures or of in-plane extended defects between TL and SL. When the field direction deviates from the (a, b) plane where the intrinsic pinning dominates, flux pinning force is greatly adjusted as the ratio increases up to a maximum of 7-22 at $\Theta = 0^{o}$ and 180^{o}.

In summary, mixed RE123 films prepared by off-axis PLD show a significantly increased critical current density and improved irreversibility field compared to pure RE123 films due to enhanced pinning properties. Detailed analysis of the J_c dependence on temperature and magnetic field together with model experiments on artificial multilayer structures reveal that the mainly responsible pinning centers are uncorrelated, point-like defects arising from lattice mismatch induced stress fields. These improved current carrying properties will open one way to enhance the performance of RE123 based coated conductors in higher magnetic fields.

References

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Funded by
BMBF