Superconducting properties of production 2G HTS wire based on YBCO with Y_2O_3 nanoparticles in magnetic field up to 16 T

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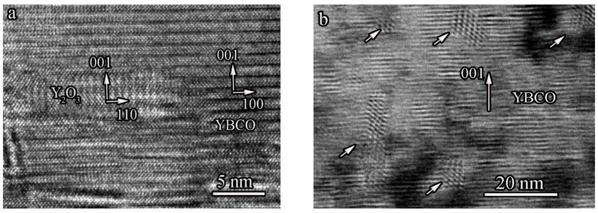
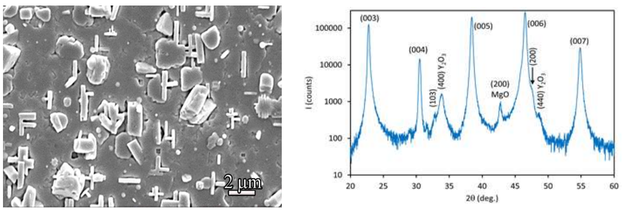
ABSTRACT

We performed characterization of superconducting properties of production 2G HTS wires based on YBCO with Y2O3 nanoparticles, which were developed recently specifically for application in high magnetic field [1], including magnets for compact fusion reactors and particle accelerators. We measured magnetization curves using vibrating sample magnetometer (VSM) in the Quantum Design PPMS (in the 0-9 T range, at 4.2-77 K) and a Cryogenics magnet (in the 0-16 T range, at 20 and 77 K). In-field performance was accessed by calculating lift-factors (LF) as the ratio of a sample's magnetic moment at a certain temperature and magnetic field to that of the same sample at 77 K, 0 T. We will discuss the application of Zhang's [2] fit model, to extrapolate the magnetic field dependences of lift-factors to 20 T. We also measured resistivity curves of the samples using PPMS in the field range from 0 to 9 T, and the samples were rotated from orientation H||c (θ = 0°) to H||ab (θ = 90°) at 30° increments. The curves were obtained by the 4-probe technique with a 100 mA measuring current. The microstructural characterization was performed by TEM, and it confirmed the presence of semi-coherent Y2O3 nanoparticles in the YBCO film matrix. In the talk, we will discuss the correlation between the HTS layer microstructure in the samples and the magnetic field, temperature and angular dependences of their superconducting properties.

MICROSTRUCTURE & XRD



Bright field TEM images showing semi-coherent Y_2O_3 nanoparticles in the YBCO matrix. (a) Platelet-shaped (100)-oriented Y_2O_3 nanoparticle. (b) (110)-oriented Y_2O_3 nanoparticles (arrowed). Particles of this orientation type are always observed as moiré features, which suggests their relatively low aspect ratio with a very small size in the 5-20 nm range.

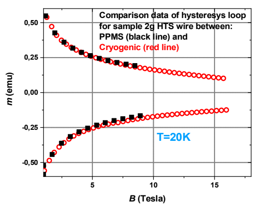


(a) SEM image of a YBCO film surface. The elongated rectangular particles are the (100)- and (010)-oriented YBCO grains; the particles with the smaller aspect ratio are secondary phase inclusions. (b) θ-2θ X-ray diffraction scan of a YBCO wire showing the (001)-preferred out-of-plane YBCO texture and low intensity peaks of misoriented YBCO grains and Y_2O_3 nanoparticles.

EXPERIMENTAL METHOD

Measurement systems used in this study, enabling magnetic fields up to 9 T, PPMS (left), and 21 T, Cryogenic (right), in the 0.3-300 K temperature range .

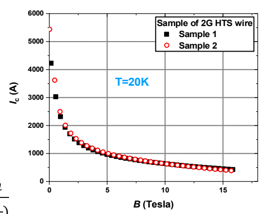
HYSTERESIS LOOP & CRITICAL CURRENT



Segments of typical hysteresis loops for the same sample of 2G HTS wire and measured in PPMS (black line) up to 9 T and in Cryogenic (red line) up to 16 T at 20 K

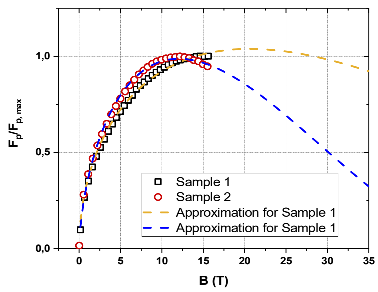
Bean model:

$$J_c = \frac{-20\Delta m}{a(1-\frac{a}{3b})}$$

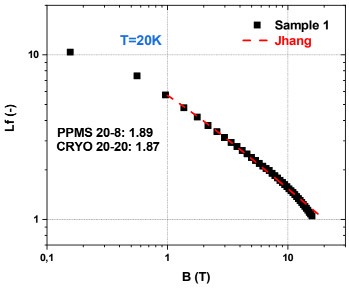


Magnetic field dependences of critical current for different two 2G HTS wire samples calculated using the Bean model from hysteresis loops measured up to 16 T at 20 K.

PINNING FORCE & LIFT FACTOR

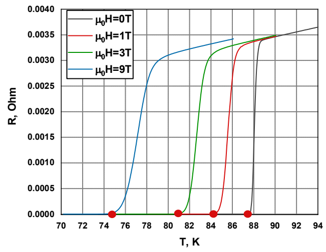


For approximation of pinning force, we use a two-mechanism model by Küpfel at. all [3] proposed for irradiated samples. This model attributes the enhancement of critical current after irradiation to the radiation-induced nanosize defect clusters acting as new pinning centers. In our case the nanosize defect clusters are Y_2O_3 nanoparticles and misoriented YBCO grains.

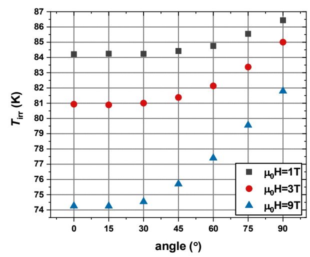


Extrapolation using the Zhang's fit model to extrapolate the magnetic field dependences of lift-factors to 20 T.

IRREVERSIBILITY TEMPERATURE

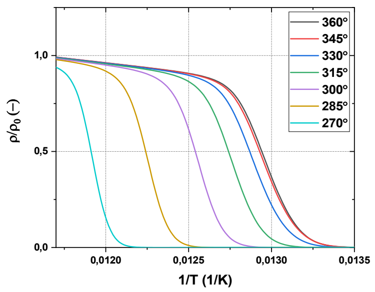


Typical curves of resistivity temperature dependence measured in magnetic fields up to 9 T. Red dots mark the irreversibility temperature as a beginning of transition with the 50 µOhm criterion.

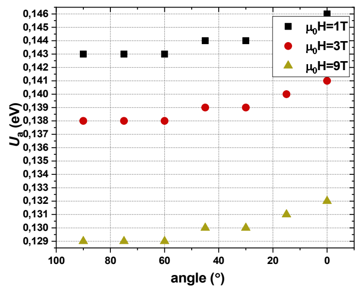


Angle dependence of irreversibility temperature (T_{irr}). We clearly observed a T_{irr} peak in the *H||ab* orientation (90°).

ACTIVATION ENERGY



Resistive transition of reference sample in logarithmic scale: log(*ρ*/*ρ*0) vs. 1/T.



Angle dependence of the activation energy in applied magnetic field up to 9T. The activation energy derived from the log(*ρ*/*ρ*0) against 1/T plots was almost constant in the whole angular range, with a small peak at *H||ab*.

CONCLUSIONS

- We systematically studied the superconducting properties of production 2G HTS wires based on YBCO with Y_2O_3 nanoparticles in magnetic field up to 16 T in the temperature range from 20 to 77 K.
- We calculated the absolute values of critical current at 77 and 20 K using the Bean model, and they correlated well for the same samples measured with the two different tools: PPMS and Cryogenic.
- The critical temperature, irreversibility temperature and activation energy decrease with increasing magnetic field.
- There is a small peak of irreversibility temperature T_{irr} and activation energy in the *H||ab* orientation We used the Zhang's fit model to extrapolate the field dependences of lift-factors at 20 K to 20 T. For example, for Sample 1 we obtained using extrapolation LF = 1.89 for the PPMS data (20-8) and LF = 1.87 for the Cryogenics data (20-20).
- For the pinning force approximation, we use a two-mechanism model by Küpfel at. all originally proposed for irradiated samples. The good correlation of the experimental data and the model confirm pinning by nanosize defect clusters, which is also supported by the microstructural analysis data.

REFERENCES

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