Title

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RADIATION DAMAGE TO BSCCO-2223 FROM 50 MEV PROTONS

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ABSTRACT

The use of HTS materials in high radiation environments requires that the superconducting properties remain constant up to a radiation high dose. BSCCO-2223 samples from two manufacturers were irradiated with 50 MeV protons at fluences of up to 5 x 10^{17} protons/cm^2. The samples lost approximately 75% of their pre-irradiation I_c. This compares with Nb_3Sn, which loses about 50% at the same displacements per atom.

KEYWORDS: BSCCO-2223. Radiation damage.

INTRODUCTION

The magnets in the vicinity of the production target in a heavy ion fragment separator are subjected to very high doses of neutrons and other nuclear radiation. To maximize efficiency in capturing the rare isotopes coming from the production target the separator quadrupoles need high gradients and large apertures. These requirements necessitate using superconducting magnets. This leads to two problems: The short-term one is removing the nuclear heating so the magnets stay superconducting. The long-term one is having all components be resistant to damage. One solution [1] is to use a High Temperature Superconductor (HTS) in a superferric quadrupole. This addresses both problems because the coil can operate at 20 – 30 K, with higher thermodynamic efficiency, and the electrical insulation can be stainless steel. Normally, the insulation is the most radiation sensitive of the materials used in a superconducting coil, but the use of stainless steel alleviates this.

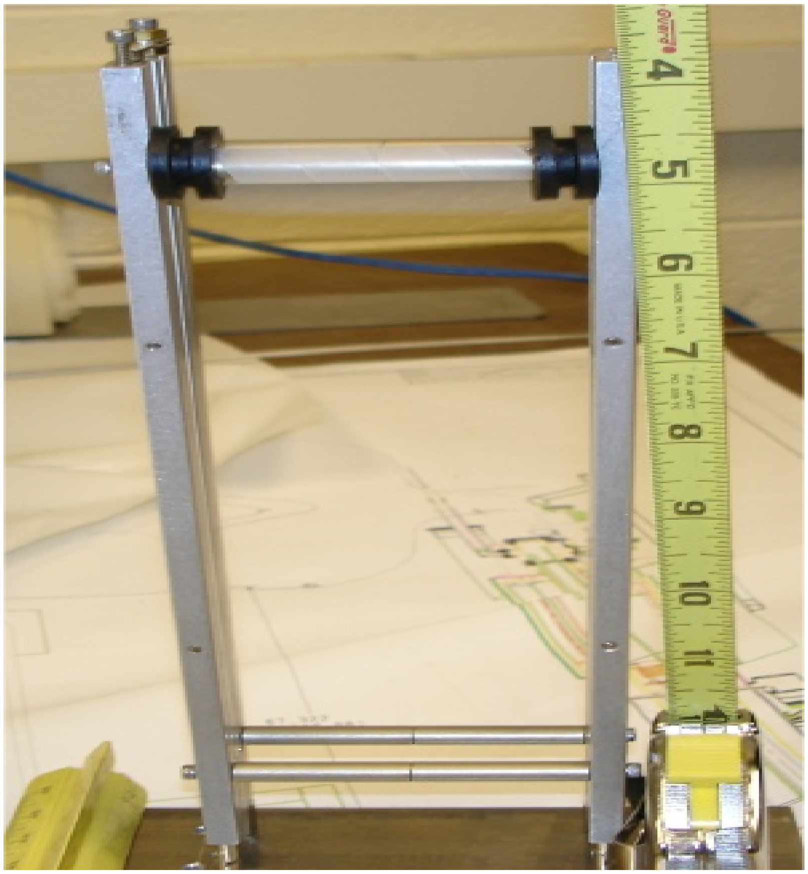

FIGURE 1. Irradiation sample holder.

The one uncertainty is the radiation resistance of the HTS material. There have been a few studies of the radiation tolerance of HTS materials [2,3], but they have been at fluxes lower than the estimated lifetime 10^{18} n/cm^2 [4] that coils will be exposed to. The current material that is under consideration is BSCCO-2223, so we have undertaken irradiation of this material.

Because the only high neutron fluxes that are readily available are in reactors where the energy spectrum does not match the very high-energy neutrons that produce most of the dose in the magnet, we substitute protons from an accelerator. This will not give us a direct estimate of the expected lifetime, but the known sensitivity [5] of Nb_3Sn to high-energy protons can be used as a reference.

EXPERIMENT

Materials

BSCCO-2223 tape from American Superconductor (ASC) and Sumitomo Electric Industries (SEI) were used for the irradiation studies. The tapes were about 4 mm wide and approximately 0.2 mm thick. The tapes were mainly silver (60-70%) and did not have a stainless steel reinforcing. The stainless steel produces long-lived activities, so was not used.

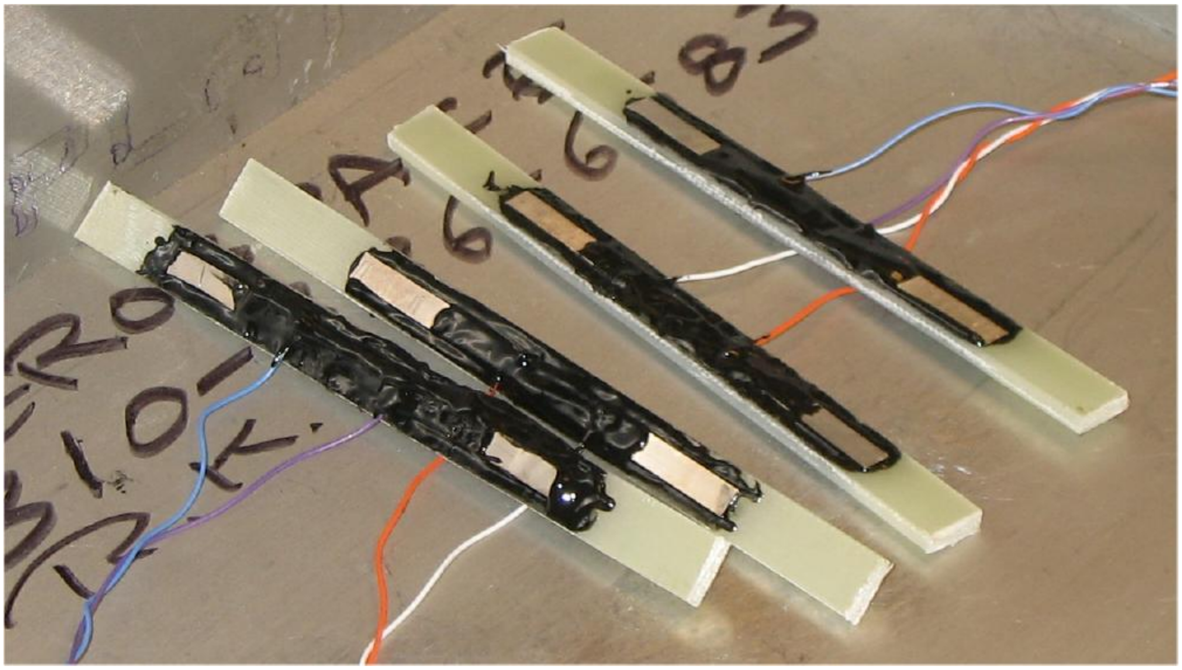

FIGURE 2. Samples after irradiation mounted on test supports. The samples are approximately 75 mm long.

Irradiations

Two samples of each tape were mounted on frames. The samples were approximately 75 mm long. Two sets of frames were used, one in front of the other, as shown in FIGURE 1. The rear frame could be dropped out of the beam by pulling a string that was run to a low-radiation area. Two samples were mounted next to each other, so the vertical beam size of 10 mm covered the combined 8 mm area. After approximately half of the irradiation, the rear sample was removed from the beam.

The irradiations were carried out at the LBNL's 88" Cyclotron using 50 MeV protons. The average beam current was about 5 μA. The beam exited the beam line through a window into the air. After losing approximately 10 MeV in the window, air and samples, the beam was stopped in a water-cooled stop. A fan was directed on the samples to keep them cool. The energy deposited in each sample was 10 W. The total number of protons delivered was 2 x 10^{18}. After cooling for seven months, the samples could be handled safely.

MEASUREMENTS

Radiographic

After cooling, the samples together with one of each that had not been irradiated were mounted on G10 pieces with Stycast 2850 FT epoxy. The G10 holders have fibers in the plane of the tape so the thermal contraction of the BSCCO is matched, reducing the starin. Voltage taps were soft-soldered to the samples approximately 20 mm apart. Wire separation was measured for each sample to allow extraction of the 1 μV/cm criterion. Some of the samples are shown in FIGURE 2.

An autoradiogram of the samples was made to determine the irradiated area and each sample was analyzed using a Ge gamma detector and multichannel analyzer. A prominent silver-105 gamma line was used to determine the relative activation of each sample. The

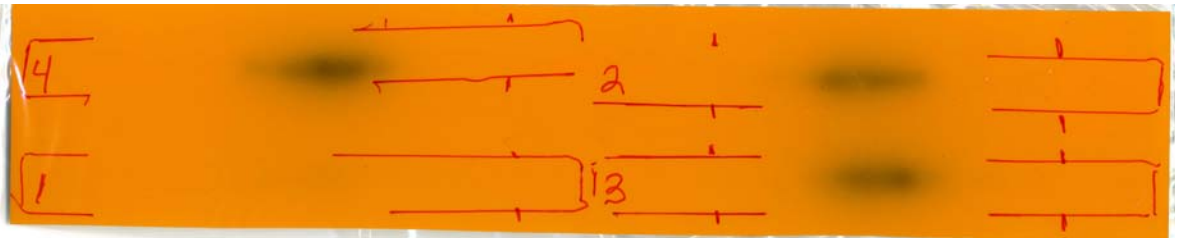

FIGURE 3. Radiogram of the samples made 7 months after irradiation.

TABLE 1. Activities of samples 7 months after irradiation in units of µCi of ^{107}Ag.

Sample	**Activity (µCi)**
ASC-1	0.9
SEI-1	11.7
ASC-2	19.
SEI-2	20.

radiograms are shown in FIGURE 3. Samples are labeled according to the manufacturers.

Measurements of the size of the activated zone were used to determine the fluence (dose per unit area). TABLE 1 lists the measured activity of each sample in terms of the residual silver-105 activity.

Critical currents

Samples were tested in an open Dewar containing liquid nitrogen without an external magnetic field. Two examples are shown in FIGURE 4. The critical current was based on a criterion of 1 µV/cm. Each sample was tested twice, but the variation in the short sample results differed by only 0.1 A. The spacing of the voltage taps is a little uncertain because the soldered connections are not small with respect to the separation; i.e., the spacing could be 17 ± 2 mm. The effect on the critical currents is relatively small since the n-value is at least 5.

RESULTS

All of the samples lost significant current transport (I_c) as a result of the irradiations. The results given in TABLE 2 are given with respect to the assumed irradiation dose. The n-values are also given. It is obvious from the radiographic results shown in FIGURE 3 and in TABLE 1 that one sample, ASC-1, received very little fluence.

Before the samples were irradiated a filmstrip was briefly irradiated to assure the beam was correctly placed. Unfortunately, during the irradiation when only the two front samples were in place, a block supporting the frames broke. Because the area was very radioactive another film was not illuminated when the problem was fixed. It appears the positioning was not identical to the original one. This turned out to be fortuitous since

TABLE 2. Transport current in samples as a function of assumed dose, together with the n-values.

Sample	**I_c (Amps)**	**n-value**
ASC reference	66	9.5
SEI reference	82.7	10.3
ASC-1	6.	2.5
SEI-1	15.1	5.3
ASC-2	18.8	8.7
SEI-2	25.9	6.3

TABLE 3. Critical current ratios scaled with activity.

Sample	I/Iref
ASC reference	1
SEI reference	1
ASC-1	0.1
SEI-1	0.2
ASC-2	0.3
SEI-2	0.3

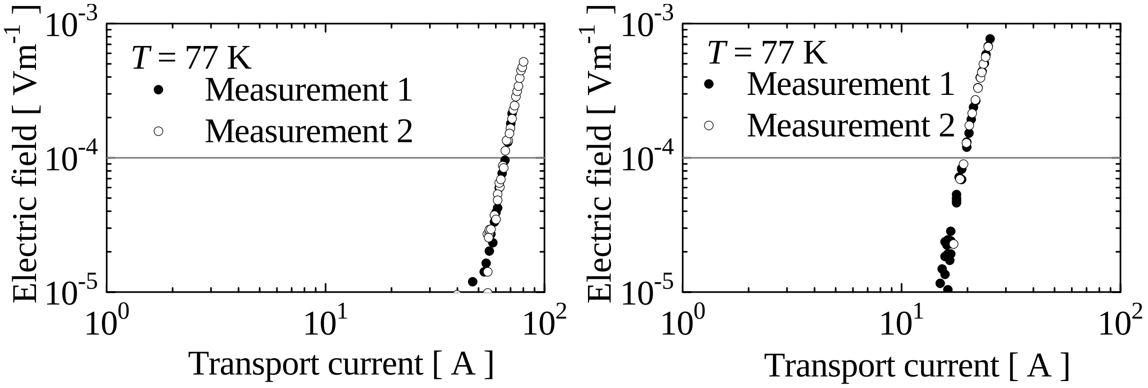

FIGURE 4. Voltage versus current measurements for the ASC reference sample and ASC-2.

ASC-1 got very little dose. The beam changed vertical position, so that SEI-1 received 3 x 10^{17} p/cm^2 before it was removed from the beam. The repositioned samples, ASC-2 and SEI-2, then received 5 x 10^{17} p/cm^2. This is consistent with the activities given in TABLE 1. The results, scaled by the amount of 105-silver are given in TABLE 3, together with the reference samples. They are presented as the ratio to the initial I_c in the reference sample.

During the mounting of the samples, ASC-1 did not get securely attached to the G10 support. We believe the sample was not adequately supported during testing and the local strain caused a reduction in I_c. Given that it experienced little beam, the measurements on ASC-1 are not included in the final results

COMPARISON WITH OTHER RESULTS

Snead [5] measured the loss of I_c in Nb_3Sn using 30 GeV protons. To compare with these results, we calculated the number of displacements per atom (dpa) by using the Monte Carlo Radiation Transport Code, PHITS [6,7]. The results are given in TABLE 4.

A previous study of high-energy neutron irradiation at 5 x 10^{15} n/cm^2 showed [2] no change in I_c. Reactor irradiation at fluence of 4 x 10^{17} n/cm^2 showed an enhanced I_c [3]. A similar effect in Nb_3Sn has been observed [8]. This enhanced I_c is not observed in NbTi. No enhancement of I_c was observed in our measurements, although the fluences were approximately the same as in [2].

DISCUSSION

Based on similar dpa's it appears that BSCCO-2223 is about a factor of two more sensitive to proton-induced damage than Nb_3Sn. There are several cautions that need to be considered with this statement. The irradiations were made at room temperature and might

TABLE 4. Comparison of the results with those obtained after irradiation with 30 GeV-protons [5] on Nb_3Sn at the same dpa. Data are the ratio I/I_0.

dpa	Nb_3Sn	BSCCO-2223
0.0078	0.75	0.2
0.013	0.5	0.3

not apply to using the material at 20 – 30 K. NbTi shows an annealing effect when it is first irradiated at 4 K and then warmed to room temperature before cooling and testing [5]. Nb_3Sn does not show any annealing in the same cycle. We have assumed that BSCCO behaves like Nb_3Sn and work by Ballarino [2] shows little difference between irradiation at room temperature and irradiation at 77 K. However, it cannot be completely ruled out. If there is annealing, then the radiation resistance relative to Nb_3Sn may be less than measured.

It is not completely clear that using displacement per atom is the correct way to obtain correlations between different irradiation systems. Thus while we can repeat the irradiation and simultaneously irradiate an Nb_3Sn sample, we cannot make a good comparison with high-energy neutron irradiation. Snead [5] did compare NbTi irradiated with both 30 GeV protons and reactor-spectra neutrons and observed very small differences. This gives some confidence the results are useful in predicting the lifetime of BSCCO-2223 in a high-energy neutron environment.

A more troubling issue is the low I_c measured for samples that were not irradiated. The expected critical currents of both the ASC and SEI tapes is above 100 A at 77 K. At present we do not have a good explanation for this discrepancy.

Since BSCCO-2223 is a first generation HTS material, it will shortly become unobtainable. Thus its use in a magnet that will be used a decade down the road is unlikely. New studies need to be carried out on materials like YBCO or BSCCO-2212. Studies made in 1991 [9] showed an increase in J_c at reactor-spectra neutrons at fluences up to 2 x 10^{18} n/cm^2 for YBCO. This is the appropriate fluence expected in the proposed fragment separators, although at a lower neutron-energy.

SUMMARY

Proton irradiations and subsequent critical current measurements on samples of BSCCO-2223 from two manufactures show a reduction in Ic that is about a factor of two lower than that observed in Nb_3Sn. In terms of using the material in a fragment separator, this is not a major problem, given the uncertainties in the measurements and interpretation. In the worst case the lifetime is reduced by a factor of two, meaning the magnets must be replaced every ten years instead of every twenty years. New studies on second-generation materials are needed before using HTS materials in any proposed fragment separator.

ACKNOWLEDGEMENTS

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