Effect of neutron irradiation on critical currents of some REBaCuO superconducting tapes considered for magnets of fusion reactors

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The effect of neutron irradiation on flux pinning and critical temperature of several commercial REBaCuO superconducting tapes was tested inductively (using vibrating sample magnetometer in magnetic field up to 9 T) and by SQUID magnetometer, respectively. The irradiation was conducted in the LVR-15 fission reactor of the Research Centre Řež with doses 1 10^{22} m^{-2} and 2.1 10^{22} m^{-2}. The neutron irradiation had either no effect critical temperature or depressed it. In all tapes I_c at self-field was slightly depressed, the irradiation effect on superconducting currents at higher magnetic fields differed in dependence of the tapes' preparation technology and was in all cases temperature- and magnetic field-dependent. It was most pronounced in the case when the pinning structure consisted mostly of rather weak point-like defects, while a weaker effect was observed in the Zr-doped tapes, where a strong pinning by the correlated columnar structure of BZO is supposed.

SAMPLES: ≈ 1.5 x 1.5 mm^2 , RE-$Ba_2Cu_3O_y$, cut from the tapes 3 – 10 mm wide, made on substrates of Hastelloy and stainless steel; the superconducting tape was about 0.8 - 3 μm thick. $I_c=8\Delta m/[a^2b(1-a/3b)]$, $a \le b$ being the sample dimensions perpendicular to the field direction, in mm, m the magnetic moment in emu, I_c (A). I_c was calculated for a tape 4 mm wide. Magnetic field normal to the tape plain.

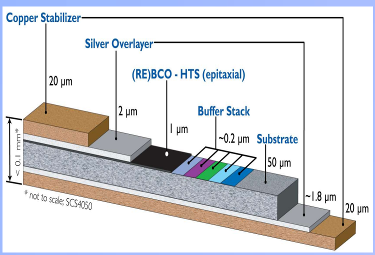

Fig.1 A typical REBCO wire construction

Table 1 The tapes' composition.

producer	technique	substrate	buffer layers	HTSC
SuNAM	IBAD/RCE	Hastelloy	$Al_2O_3/Y_2O_3/MgO/LaMnO_3$	Gd-123
SuNAM	IBAD/RCE	Stainless steel	$Al_2O_3/Y_2O_3/MgO/LaMnO_3$	Gd-123
SuperPower	IBAD/MOCVD	Hastelloy	$Al_2O_3/Y_2O_3/MgO/LaMnO_3$	Y-123 + Sm or Gd
SuperOx	IBAD/PLD	Hastelloy	$Al_2O_3/Y_2O_3/MgO/LaMnO_3/CeO_2$	Gd-123

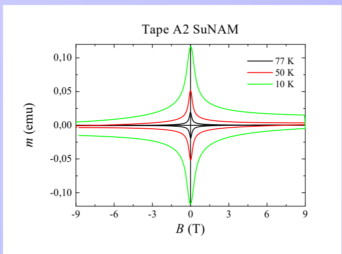

Fig. 2 The magnetic hysteresis loops of the SuNAM A2 tape.

Table II. The engineering currents (10 K, 50 K, and 77 K), the lift factors (under slash, 50 K and 77 K), and the irreversibility field at 77 K before irradiation.

Sample	I_c (A) 77 K, 0 T	B_{irr} (T)	I_c (A) 50 K, 0 T	I_c (A) 50 K, 9 T	I_c (A) 10 K, 0 T	I_c (A) 10 K, 9 T
SCS4050 7.5%Zr	124	8	556/4.48	38/0.31	1690/13.63	252/2.03
SCS4050 15%Zr	118	8	511/4.33	35/0.22	1555/13.18	230/1.95
SCS4050AP	77	8	393/5.1	27/0.35	1302/16.91	136/1.77
Gryaznevich	84	8	390/4.64	23/0.27	1225/14.58	130/1.55
SCS 3050 AP	91	8	417/4.58	26/0.29	1405/15.44	137/1.51
SCS 4050/1	58	8	249/4.29	21/0.36	902/15.55	138/2.38
SCS 4050/2	55	7	244/4.44	18/0.33	865/15.73	130/2.36
SuperOx	120	7.3	397/3.31	23/0.19	1100/9.17	150/1.25
SuNAM A1	142	7.7	419/2.95	13/0.092	1040/7.32	90/0.634
SuNAM A2	128	7.3	369/2.88	10/0.078	831/6.49	73/0.57
SuNAM A3	146	7.3	438/3.00	14/0.096	1040/7.12	89/0.61
SuNAM A4	83	7.3	280/3.37	7/0.084	808/9.73	75/0.904
SuNAM B1	67	3.5	178/2.66	0.1/0.001	410/6.12	15/0.22
SuNAM B2	67	7.1	178/2.66	6/0.09	400/5.97	42/0.627
SuNAM B3, B4	135	7.5	442/3.27	12/0.089	1100/8.15	93/0.69
SuNAM C1	224	8.8	631/2.82	19/0.085	1430/6.38	127/0.567
SuNAM C2	218	8.5	605/2.78	16/0.073	1355/6.21	117/0.537
SuNAM C3	209	8.5	578/2.77	18/0.086	1410/6.75	121/0.579
SuNAM C4	171	8.5	480/2.81	15/0.088	1135/6.64	100/0.585
SuNAM	156	7.5	468/3.00	14/0.09	1062/6.81	95/0.61

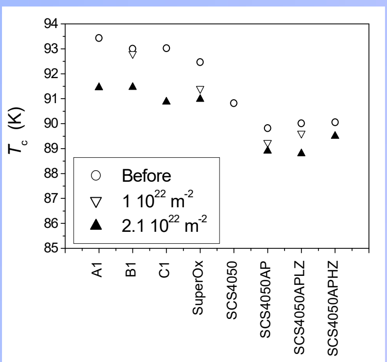

Fig. 3. Change of critical temperature due to neutron irradiation by the dose 2.10^{22} m^{-2}

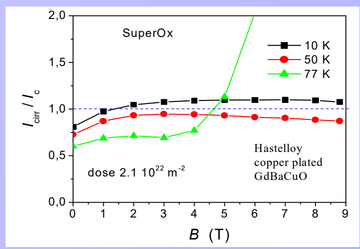

Fig. 6. Effect of neutron irradiation on the inductively measured I_c on the sample SuperOx. Ratio of I_c after irradiation, and that before it.

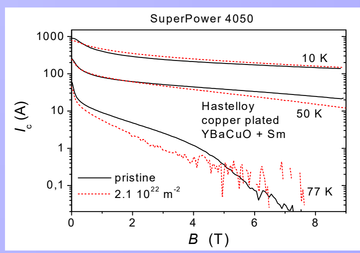

Fig. 7 Effect of neutron irradiation on the inductively measured I_c on the sample SuperPower 4050. The black lines are before irradiation, the red and green ones after irradiation.

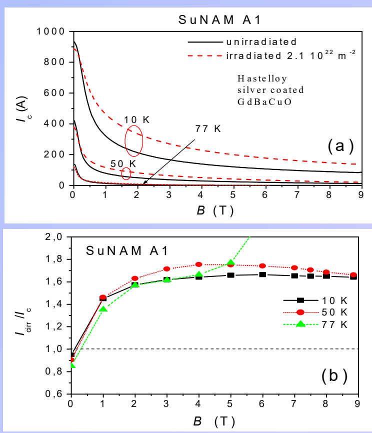

Fig. 4. Effect of neutron irradiation on the inductively measured I_c on the sample SuNAM A1. The black lines are before irradiation, the red ones after irradiation. (a) Linear plot, (b) ratio of I_c after irradiation, and that before it.

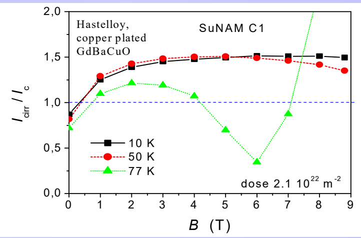

Fig. 5. Effect of neutron irradiation on the inductively measured I_c on the sample SuNAM C1. Ratio of I_c after irradiation, and that before it.

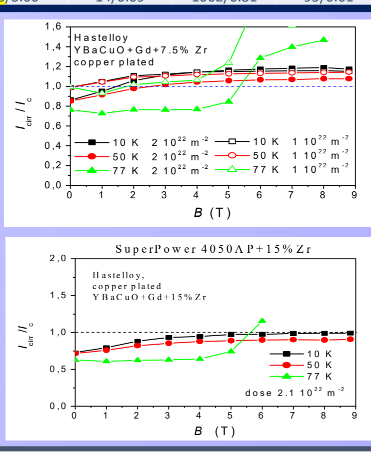

Fig. 9 Effect of neutron irradiation on the inductively measured I_c on the sample SuperPower 4050AP doped by Zr. Ratio of I_c after irradiation, and that before it. Upper figure 7.5 % Zr, lower figure 15% Zr

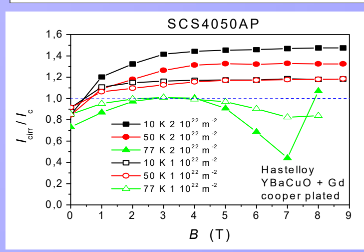

Fig. 8 Effect of neutron irradiation on the inductively measured I_c on the sample SuperPower 4050AP. Ratio of I_c after irradiation, and that before it.

CONCLUSIONS

1) At 77 K, self-field all the investigated intact tapes satisfied the basic requirement of $I_c \geq 50$ A.
2) At low temperatures below 50 K the SuperPower tapes doped by Zr excelled in the whole field range.
3) At low magnetic fields, especially at and above 50 K, the best results showed the SuNAM copper plated tapes, both on Hastelloy and stainless steel substrates. They achieved $I_c(0\ T, 77\ K) \geq 200$ A . These tapes exhibited also good results at 10 K, especially at low fields.
4) Neutron irradiation slightly reduced I_c at low magnetic fields in all investigated samples. In intermediate and high magnetic fields the irradiation effect depended on temperature and the tape technology. In general, I_c in this field range was significantly enhanced in all SuNAM tapes, where mostly point-like pinning is supposed. Only slightly enhanced or not at all was the effect in the samples with originally strong pinning, like SuperOx and SuperPower, especially those doped by Zr, where creation of a correlated pinning structure of $ZrBO_3$ columns is expected.
5) The irradiation slightly depressed the rather high T_c in the SuNAM and SuperOx samples (Gd-123), having much smaller effect on the lower T_c of SuperPower AP samples of all kinds (Y-123+RE).
6) The results prove that modern tapes are able to sustain neutron irradiation up to the dose of 2.1 10^{22} m^{-2}, which we believe is not far below the full-life dose of fusion reactors.