Mass Production of Low-Cost $LREBa_2Cu_3O_y$ Bulk Superconductors for Railway Systems Using a Novel Seed in the Batch Process

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A batch production method for fabrication of $LREBa_2Cu_3O_y$ (LRE: Sm, Gd, NEG) "LRE-123" pellets in air and Ar-1% O_2 using a novel thin film of Nd-123 seeds grown on MgO crystals has been developed at the Railway Technical Research Institute (RTRI). A novel thin film of Nd-123 seed grown on a MgO crystal, compatible with all LRE-123 materials, is the key prerequisite for successful batch production. As a result, we are able to fabricate Sm-123, Gd-123, and NEG-123 compounds with large single-grain pellets (> 45 mm), exhibiting high pinning and good quality at a dramatically reduced cost. Further, we made more than 130 single-grain pucks within a couple of months. Taking advantage of the single-grain batch processed material we constructed a chilled levitation disk, which was used during an RTRI open day. The present results prove that a high-performance good-quality $LREBa_2Cu_3O_y$ material can be comfortably scaled up from laboratory to industrial production.

The performance of $LREBa_2Cu_3O_y$ material has reached the level necessary for industrial applications including railways, and we believe that bulk superconducting magnets will in the near future enter the market as basic components for various utilities. In all these cases a large number of pieces with equally high quality are required. Batch-processing of LRE-123 materials with uniform properties is the essential requirement in this process. For batch production of LRE-123, we used a special box furnace with the utility volume of 20x50x25 cm^3, in which a vertical temperature gradient could be created (see Fig. 1). Twelve to twenty LRE-123 pellets were placed on yttrium-stabilized ZrO_2 rods inside the furnace. Subsequently, the MgO crystals covered by the Nd-123 thin film were placed centrally on the top of each pellet and they were then melt-grown in air. The melt textured samples were eventually annealed at 400-450 ºC for 250-450 hours in flowing pure O_2 gas.

Recently, for the first time in the world, we successfully and repeatedly batch-processed multiple high-quality melt-textured $LREBa_2Cu_3O_y$ blocks (see Fig. 2). Trapped field experiments confirmed that all batch-processed samples were single domain and high performance. The superconducting transition measured at various positions of the batch-processed single-grain Gd-123 material was sharp (around 1 K width) with the highest onset T_c around 93.5 K, similar to the samples melt-processed in a reduced oxygen atmosphere. The self-field J_c of 70 kA/cm^2 was achieved in various positions of the pellet at 77 K and with H//c-axis. The trapped field observed in the best 45 mm single-grain puck of Gd-123 was in the range of 1.35 T and 0.35 T at 77.3 K and 87.3 K, respectively (see Fig. 3). We thus produced more than 130 single-grain pucks within a couple of months. The reproducible quality and quantity of the batch processed LRE-123 bulks allowed us to construct a home-made levitation disk. This is one of the important steps on the way to potentially replace the superconducting coils on a Maglev vehicle by bulk super-magnets cooled by liquid nitrogen, which is far more economic than the present method, or by cryogen-free refrigeration. The disk was used for the public during the RTRI open day on October 9, 2010. More than 150 children stood on the disk and enjoyed the experience of levitation (see Fig. 4). We also loaded a maximum weight of around 35 kg with the gap maintained at around 5 mm. Further improvements to the levitation disk (e.g. by adding an additional ring of magnets) are underway, and these will make it possible to levitate adult people. These results prove that the novel seeds have a great potential for batch-processing of large single grain LRE-123 pucks, reducing the production time and cost.

In summary, the batch-processed LRE-123 composites are suitable for industrial super-magnet applications including Maglev, for power storage units using HTS flywheels, and for current-limiting devices etc. The present technology opens the way for more practical and reliable next generation railway systems.

Fig. 1. Furnace designed for batch production of LRE-123

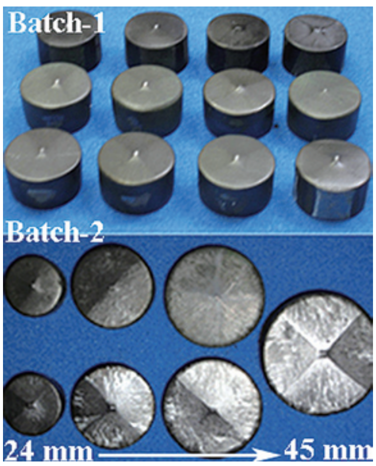

Fig. 2. A photograph of batch processed as-grown LRE-123 samples prepared by the cold seeding method using a Nd/MgO film as a seed crystal

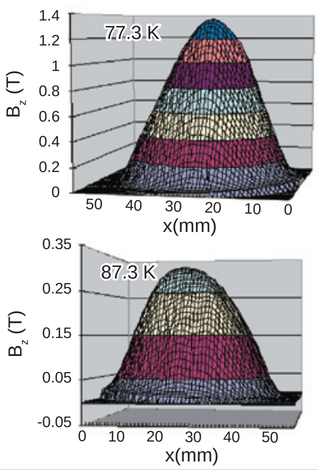

Fig. 3. Performance of the batch processed 45 mm diameter Gd-123 single grain material at 77.3 K and 87.3 K. The trapped field of 1.35 T and 0.35 T was achieved in the remnant state

Fig. 4. Levitation of child using a repulsive force between home made batch processed LRE-123 pellets and home made permanent magnet disk