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Authors: Sait Barış Güner

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# Effect of Gd211 Addition on the Vertical Levitation Force of Gd123 Superconductors

Sait Barış GÜNER\*<sup>1</sup>

## Abstract

We investigated the microstructure and magnetic properties of Gd123:Gd211 = 1-y : y (y = 0.0, 0.1, 0.2, 0.3, 0.4 and 0.5) bulk superconductors with the diameter of 13 mm and thickness of 5 mm fabricated by melt-textured method. The vertical levitation force between melt-textured bulk superconductors and a permanent magnet is measured at 30, 40, 50, 60, and 77 K under zero-field-cooling (ZFC) and field-cooling (FC) regimes by Magnetic Levitation Force Measurement System (MLFMS). The phase and microstructures properties of all samples are determined by SEM (Scanning Electron Microscope) and analysed that the pore sizes in the matrix decrease by adding Gd211 particles into Gd123 samples. The measurements of superconducting characteristics showed that the maximum vertical levitation forces of the G1 sample were noted as 3.04, 2.30, 1.53, 0.91 and 0.16 N at the temperatures of 30, 40, 50, 60 and 77 K, respectively. The present results perform that a high-performance good-quality GdBCO can improve from laboratory conditions to technological applications for large scale levitated system.

**Keywords:** High-T<sub>c</sub> superconductors, Magnetic Levitation Measurements, Microstructure

## 1. INTRODUCTION

Melt-textured (Re)BCO (Re= Nd, La, Y, Sm, Eu and Gd) and BSCOO high T<sub>c</sub> superconductors are known as useful materials for research works [1-5] and many applications such as energy storage systems, generators, superconducting magnetic bearings, motors, flywheel, and levitated transportation systems [6-11]. For trapped field and levitation applications, it is essentially significant to rise the critical current density (J<sub>c</sub>). Additionally, the critical current density of (Re)BCO superconductors can be increased by some ways: i) the enrichment of flux pinning with the homogeneously fine (Y or Gd)<sub>2</sub>BaCuO<sub>5</sub> (Y-Gd211) inclusions in (Y or Gd)Ba<sub>2</sub>Cu<sub>3</sub>O<sub>7</sub> structure, ii) artificial behaves such dislocations, promoting faults, twins etc., in the Y(Gd)123 matrix iii) the grain configuration to achieve the weak-link nature of grain boundaries [12,13]. According to Xu et al., the addition of Gd211 particles in the Gd123 bulk superconductors is an effective mode to develop the J<sub>c</sub>.

J<sub>c</sub> of bulk superconductor samples is improved at low temperatures (<77K) [14-17], and significantly enhanced higher levitation force and trapped field. Up till now, numerous study groups have performed lots of works about superconductors in some levitation force and trapped field measurements of bulk superconductor samples [14-18]. Nariki et al. reported high trapped field value of 6.7 T (at 55 K) of GdBaCuO bulk with silver [15]. Ainslei et al. fabricated GdBCO-Ag bulk sample and also noted trapped field with 3.11 T and 6 T at 65 and 40 K, respectively [16]. A world record of 17.6 T trapped field at 26 K has been accomplished (Cambridge) with silver added GdBCO bulk sample [17]. Kim et al. performed GdBCO-CeO<sub>2</sub> bulk with artificial holes exhibits good magnetic levitation, 138.4 N, at 77 K [18]. Nariki et al. measured levitation force of GdBCO at the different temperatures of liquid O<sub>2</sub> (90.2 K), Ar (87.3 K) and N<sub>2</sub> (77.3 K) [19]. In our previous work, the effect of Gd<sub>2</sub>BaCuO<sub>5</sub> (Gd211) adding on electro-magnetical and structural properties of

GdBa<sub>2</sub>Cu<sub>3</sub>O<sub>7</sub> (Gd123) bulk samples was studied. Moreover, the influences of Gd211 on lateral force of Gd123 bulks at different temperatures have been worked for first time [20]. In this study, the effects of Gd211 addition into Gd123 pellet samples on the vertical levitation force at the temperatures of 30, 40, 50, 60 and 77 K is worked in the first time. In addition, SEM (Scanning Electron Microscope) analyzation of samples was investigated.

## 2. EXPERIMENTAL PROCEDURES

GdBa<sub>2</sub>Cu<sub>3</sub>O<sub>7</sub> (Gd123) and Gd<sub>2</sub>BaCuO<sub>5</sub> (Gd211) powders were fabricated using solid state reaction technique between CuO, BaCO<sub>3</sub> and Gd<sub>2</sub>O<sub>3</sub> powders. Gd211 and Gd123 powders put in a glass of bottle, shaken for 10 min. and calcined at 900 °C and 920°C for 24 h, respectively.

Calcined Gd211 powders were put into calcined Gd123 powder like Gd123:Gd211 = 1-y : y (y = 0.0, 0.1, 0.2, 0.3, 0.4 and 0.5). Ag<sub>2</sub>O (0.14 wt %) were put into the mixtures. Ag<sub>2</sub>O (0.14 wt %) were added to each mixture. The mixture was grounded for 20 min by an agate mortar After, the mixture was prepared as a pellet size with 13 mm in diameter and 5 mm in thickness under 5 tons. To determine the samples, they are noted as G0, G1, G2, G3, G4 and G5 paralleling to y = 0.0, 0.1, 0.2, 0.3, 0.4 and 0.5, respectively.

Single crystal MgO (100) seed was put as a seed specimen for the development of GdBCO grains and GdBCO pellet was put on the pellet on the alumina substrate at the center of a box furnace and melt-textured process was applied with the

furnace cycles of Fig. 1 [20,21]. The flowing oxygen process was applied at 450 °C at the centre of a cylindrical furnace.

Magnetic levitation force measurements in zero field cooled (ZFC) and field cooled (FC) regimes were realized at the temperatures of 30, 40, 50, 60 and 77 K using Magnetic Levitation Force Measurement System (MLFMS) (see in Figure 2). This system involves of the NdeBeFe cylindrical permanent magnet (PM) with a magnetic field of 0.5 T and diameter of 13 mm and thickness of 8 mm, is able to travel on the sample in the vertical and lateral directions. MLFMS was produced by the project provided by TUBITAK (Project no: 110T622- Project Manager: Sukru CELİK). The detailed knowledge of the system can be in Ref. [22]. The vertical levitation force ( $F_z$ ) versus vertical distance (z) processes were performed by first setting the sample nearly on the axis centre of the PM. Then, the measurement processes in the MLFMS was started. The measurement distance between the PM and the sample was taken as 50 mm (z direction) in ZFC regime. When the sample was cooled at z = 50 mm on the top face of the PM (where the magnetic value of PM is negligible), the  $F_z$ -z measurements were carried out throughout the vertical cross of the PM from z = 50 mm to at least distance of z = 1.5 mm, continued by a vertical cross out to z = 50 mm. Under FC regime, vertical levitation force measurements were carried out as the sample cooling at z = 1.5 mm over the PM. In addition, the measurements were performed as long as the PM was vertically transferring from z = 1.5 mm to z = 50 mm, continued by a vertical cross to z = 1.5 mm [23]. later.

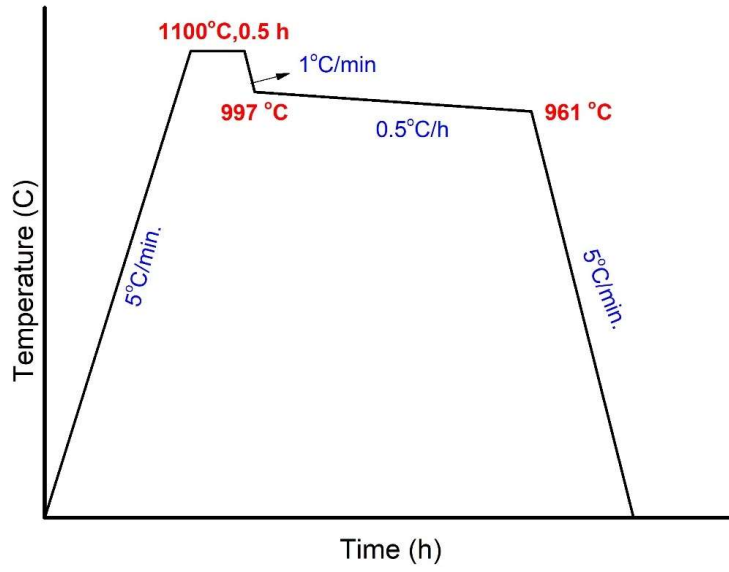


Fig. 1 Melt-textured process of all the samples



Fig. 2 The photo of magnetic levitation force measurement system.

### 3. RESULTS and DISCUSSIONS

Figure 3 displays vertical levitation force ( $F_z$ ) dependence of the vertical distance for G0, G1, G2, G3, G4 and G5 samples at 30-77 K under ZFC regime. After the samples were cooled at 50 mm in z-direction, the  $F_z$  dependence of vertical distance is measured in both descending and ascending process between the maximum distance of 50 mm and the gap distance of 1.5 mm. It can be said that the  $F_z$  value at a cooling temperature exponentially rises by reducing distance between the PM and the sample. Because the PM is gone to the superconductor, the effect of magnetic field rises in the superconductor [24]. This rise causes magnetization ( $M$ ) into sample and similarly the levitation force of superconductor sample rises. Because the levitation force can be calculated by  $F_z = m(dH/dz)$ , where  $dH/dz$  is the magnetic field dependence of z-direction and  $m$  is the magnetic moment of a superconductor.  $M (= J_c r A)$  is the magnetization of the superconductor, where  $m = MV$  is determined the magnetization per unit volume ( $V$ ),  $J_c$  is the critical current density of a superconductor,  $A$  is the sample geometry constant and  $r$  is the radius of a shielding current loop [24,25]. On the other hand; when the PM is gone away from the superconductor, the external field drops. And this case induced the decrease of levitation force. When can be observed in Fig. 3, the amount of rise of levitation force value declined with rising the measurement temperature.

The vertical levitation force ( $F_z$ ) dependence of the vertical distance ( $z$ ) for G0, G1, G2, G3, G4 and G5 at 30-77 K under FC regime is shown in Figure 4. It can be observed in Figure 4 that the levitation force indicates attractive force performance. The hysteresis loops enlarge under FC regime when the samples move in the going down/going up cycle with rising the measurement temperature for the trapped magnetic flux and caused circulating currents into the samples.

However, the going up cycle joins a repulsive force influence and declines the whole attractive levitation force values [26,27]. This case is the cause of smaller going up cycle than going down cycle. As compared Fig.3 and Fig.4, it can be said that the attractive force under FC regime is higher than under ZFC regime as the repulsive force under ZFC regime is higher than under FC regime and there is a good relation with the literature [28-30].

The maximum repulsive and attractive force values versus Gd211 content curves illustrated in Fig. 5 and Fig. 6. As can be clearly performed in these figures, the addition of Gd211 content illustrates higher repulsive and attractive force at 30, 40, 50, 60 and 77 K compared the pure sample. As analysed in Figure 5 and Figure 6 in detailed, the amount of attractive force seems to increase with rising Gd211 content from 0.1 to 0.4 compared pure sample. The reason of this case is Gd211 micro-grains can be performed as artificial pinning centres in Gd123 matrix. The maximum repulsive force at the temperatures of 30, 40, 50, 60 and 77 K are seen for G1 samples as 3.04, 2.30, 1.53, 0.91 and 0.16 N, respectively. Additionally, the maximum attractive force at the temperatures of 30, 40, 50, 60 and 77 K are seen for G1 samples as -0.98, -0.73, -0.48, -0.30 and -0.06, respectively. The optimum Gd211 addition in Gd123 system provides the increase of the pinning centres to improve superconducting characteristic performance [31-33]. Moreover, the much more addition of Gd211 content into the samples show low repulsive and attractive force at cooling temperatures because of the size increment of Gd211 micro-grains in Gd123 matrix. Indeed, the superconducting properties of Gd123 decrease with the excess Gd211 content [20,21,31,32]. Although magnetic levitation force measurements define the presence of the pinning centres in the Gd211 doped samples, SEM analysis help us to describe the Gd211 particles in Gd123 matrix as shown later.

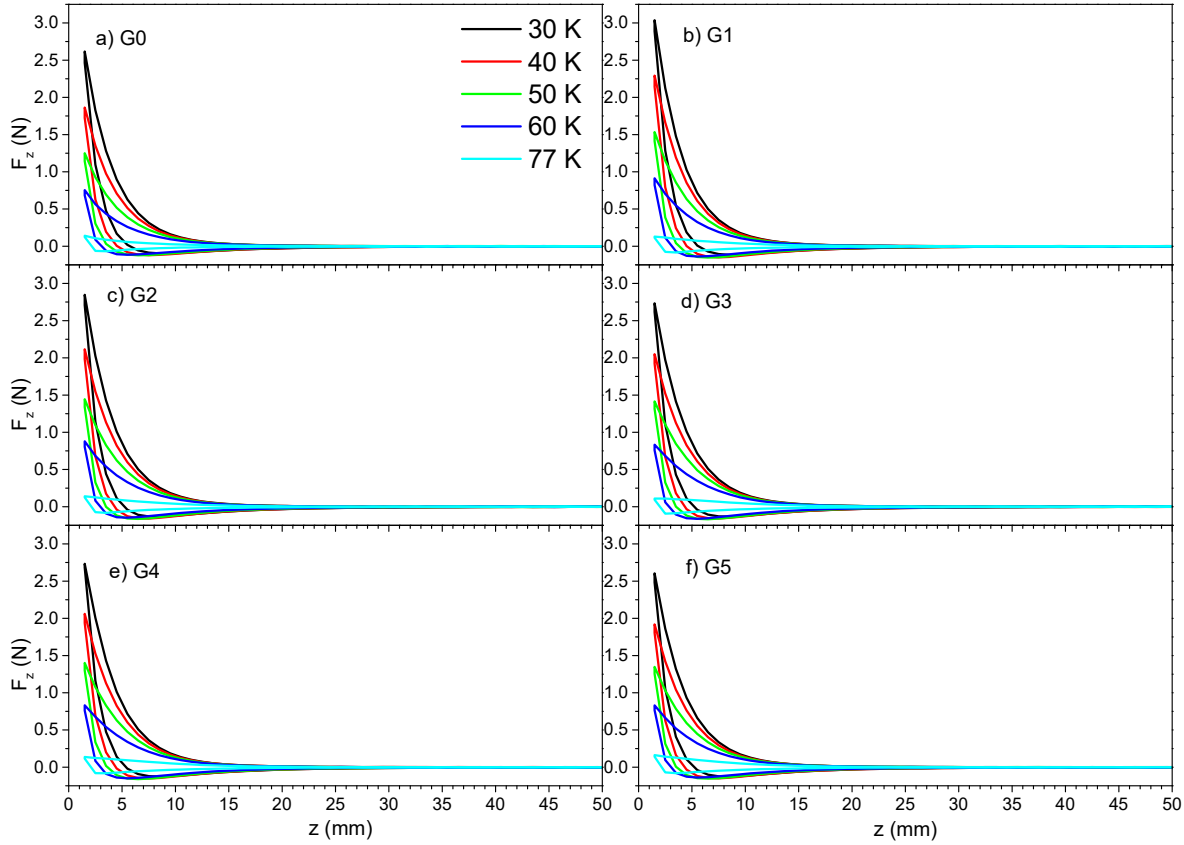


Figure 3. The levitation force versus z-direction distance for G0, G1, G2, G3, G4 and G5 samples at between 30 and 77 K under ZFC regime.

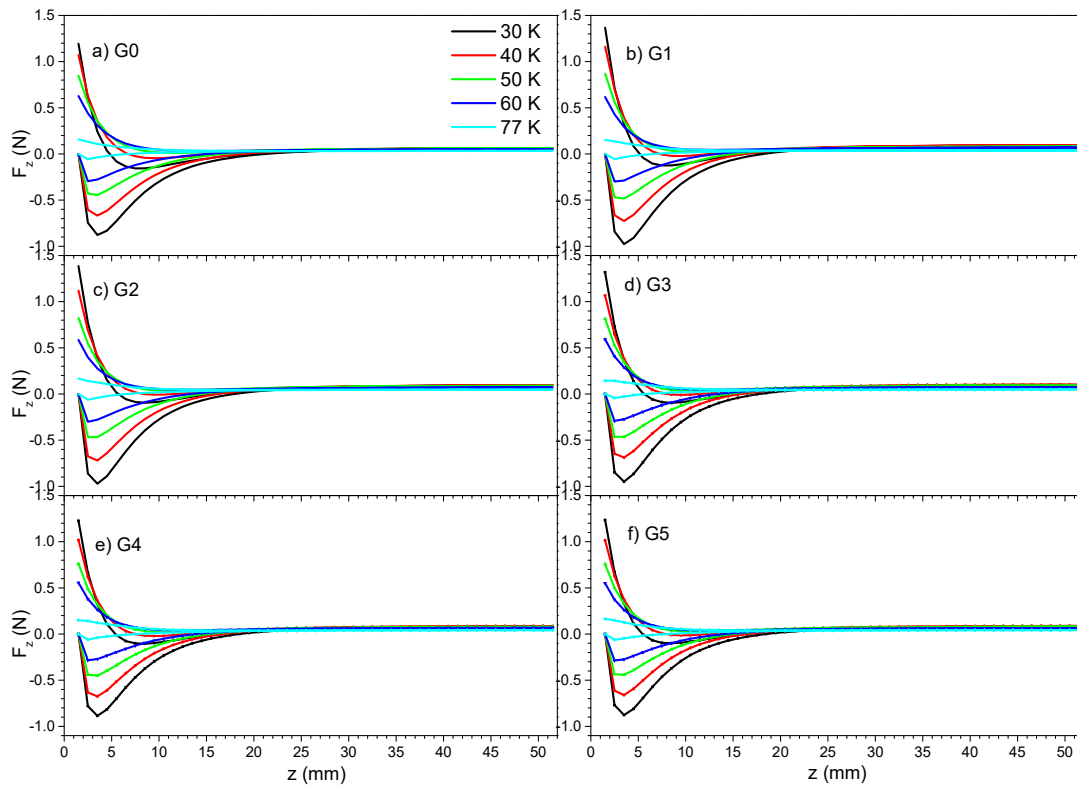


Figure 4. The levitation force versus z-direction distance for G0, G1, G2, G3, G4 and G5 samples at between 30 and 77 K under FC regime.

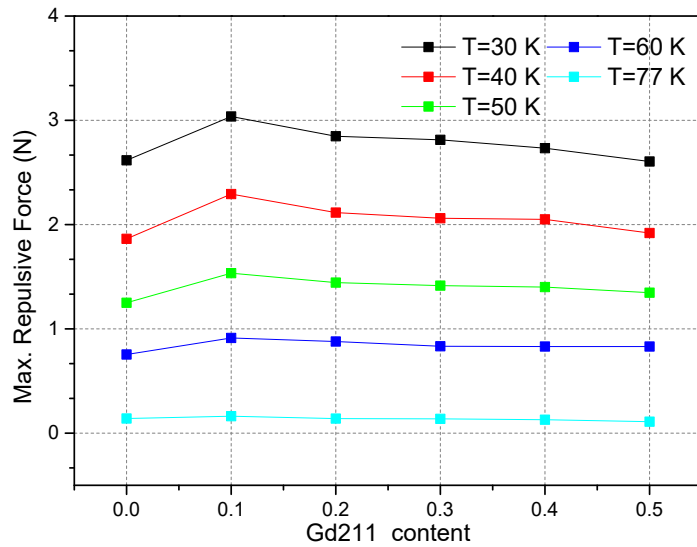


Figure 5. The maximum repulsive force versus Gd211 content in Gd123 samples at 30, 40, 50, 60 and 77 K.

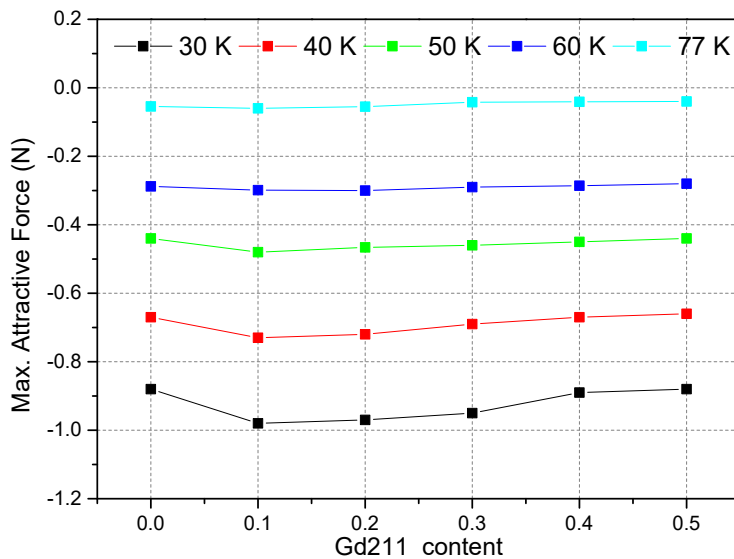


Figure 6. The maximum attractive force versus Gd211 content in Gd123 samples at 30, 40, 50, 60 and 77 K.

The SEM photographs of the G0, G1, G2, G3, G4 and G5 samples are indicated in Fig. 7 (a–e). Gd123 matrix grains appear pieces and the amount of pore is a little high in the pure sample. The pore sizes in the matrix decrease by adding Gd211 particles into Gd123 samples when the levitation force performance is improved due to the enhancement of pinning centres owing to the addition of Gd211 content, as observed in Fig. 6 and Fig. 7. Especially, the Gd211 particles fill in

the pores of Gd123 matrix for G3 sampled (see in Fig. 8-d) Excess Gd211 content, as shown in Fig. 7 (d-f), affected the increasing of non-superconducting state in Gd123 samples and the decreasing of the superconducting characteristic degree. Moreover, this case is consistent with the magnetic levitation force results compared with other Gd211 doped samples. As accomplished in SEM analysis; the Gd211 addition disappears equally in the Gd123 matrix and this result showed that Gd123 calcinated powder, Ag<sub>2</sub>O

powder and Gd<sub>2</sub>11 calcinated powder were mixed homogenously (see in Fig. 7d).

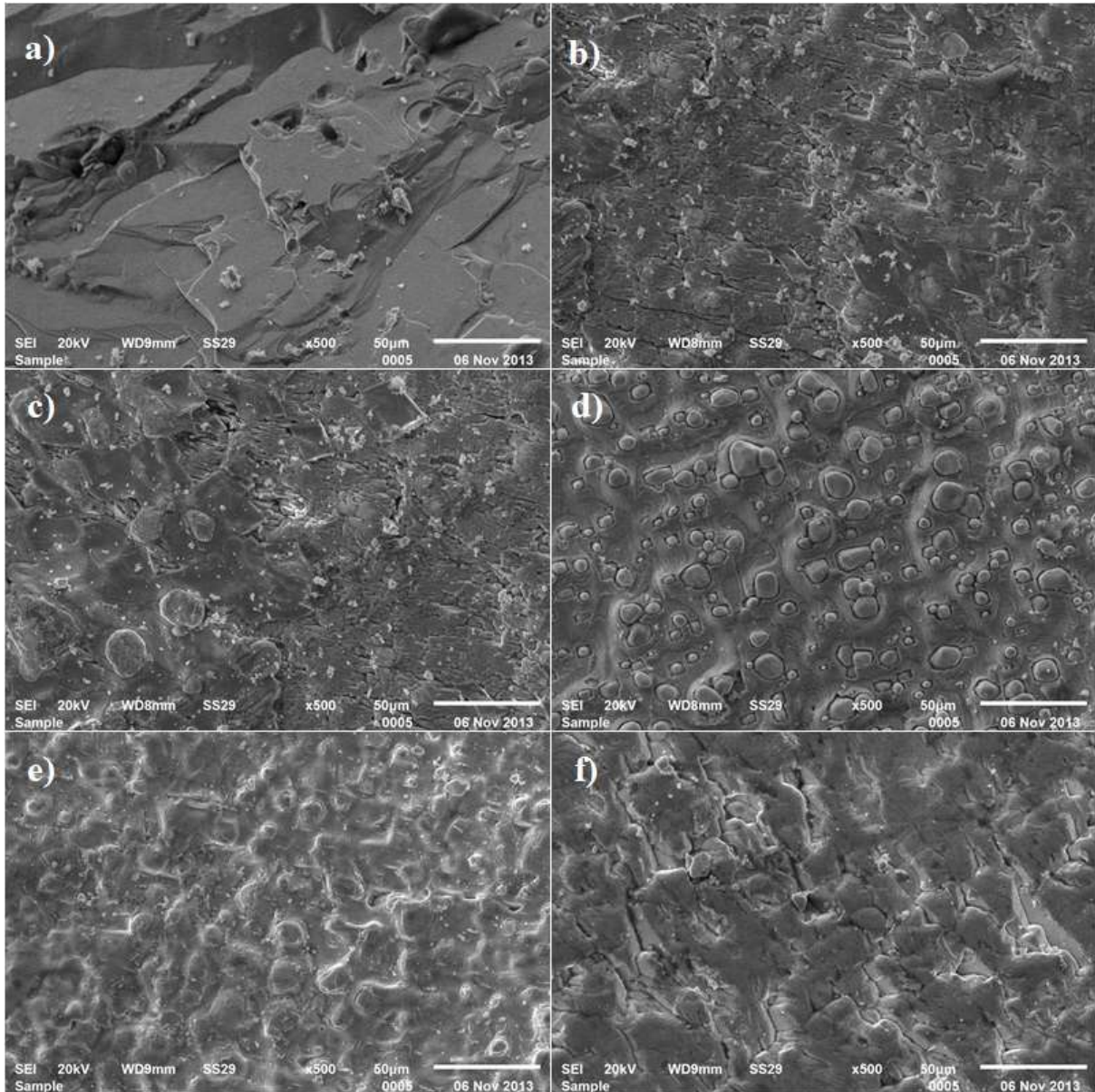


Figure 7. SEM pictures at a low magnification (x500) of a) G0, b) G1, c) G2, d) G3, e) G4 and f) G5



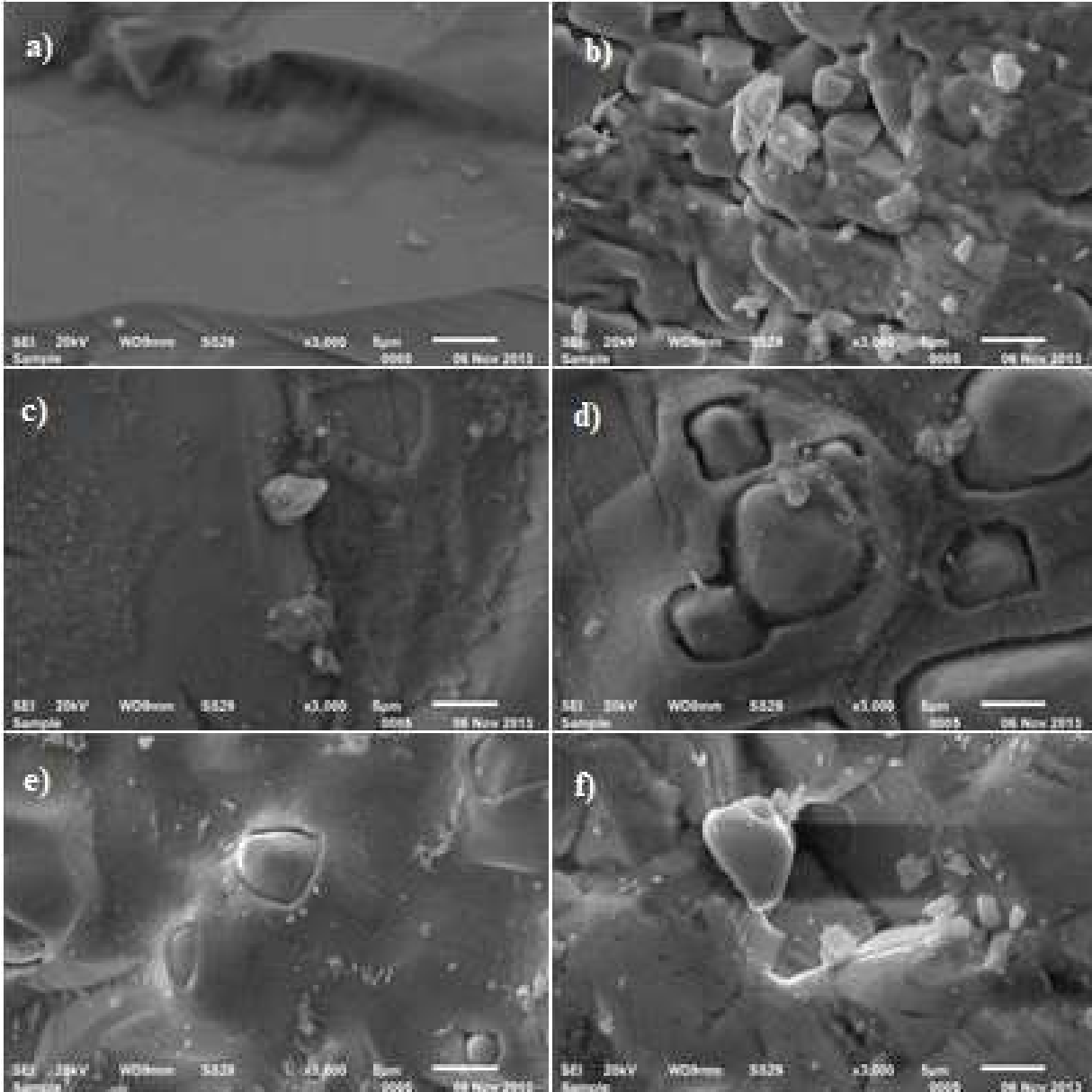


Figure 8. SEM pictures at a high magnification (x300) of a) G0, b) G1, c) G2, d) G3, e) G4 and f) G5

#### 4. CONCLUSIONS

We investigated the influences of Gd211 addition in Gd123 superconductors using MgO seed crystal by fabricated melt-textured process. It has been illustrated the vertical levitation force measurements under ZFC and FC regimes at between 30 and 77 K of these samples for the first time in this work. This study has shown that the vertical levitation force rises with reducing the cooling measurement temperatures. G1 sample has the maximum repulsive and attractive force because Gd211 particles behave as pinning centres in Gd123 matrix. Amongst these samples,

the repulsive and attractive force values drop when the amount of Gd211 content is ascended. The cause of the decline of the levitation force of samples (apart from G1) is since superconductivity fails with the much more Gd211 content. As a result, this work should perform a useful technique to produce single grain GdBCO superconductors and to enhance the technological supermagnet applications such as motors, NMR system, flywheel, wind power generation, etc.

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