# Flux pinning properties on SmBCO superconducting films with high number density of $BaHfO_3$ nano-rods at lower measurement temperatures

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In recent years, many researchers consider to apply $REBa_2Cu_3O_y$ (REBCO: RE = rare earth) coated conductors to coiled applications in a broad range of temperatures and magnetic fields. Hence, the investigation of the flux pinning properties is important.

Recently, we succeeded in controlling the size and number density ($n$) of $BaMO_3$ (BMO) nano-rods exactly. In this study, our purpose is to reveal flux pinning properties in SmBCO films with various $n$ of BHO nano-rods at various temperatures from 20 to 90 K. The films were fabricated by pulsed laser deposition (PLD) method adopting our seed layer technique at a low substrate temperature. This seed layer technique was named as "low-temperature growth (LTG)" technique. Here, we controlled doping levels of BHO in the films by alternating target technique.

As a result, the BHO nano-rods in the BHO-doped films prepared by the LTG technique became small in the diameter and had high $n$ and it was much higher than those in films fabricated by conventional PLD method in spite of the same amount of BHO. For example, the $n$ within the 5.6 vol.% BHO-doped film reached 4780 /$\mu m^2$, and the matching field ($B_\Phi$) which was calculated from $n$ was about 10 T.

All the films showed good superconducting properties such as high critical temperatures (> 90 K) and critical current density (> 1.5 MA/$cm^2$, @ 77 K). We measured the flux pinning properties at a broad range of temperatures under magnetic fields of 0 – 18 T ($B$//$c$). Irreversibility fields at 77 K were 10 T for the 1.6 vol.% BHO-doped film and 15.1 T for the 5.6 vol.% BHO-doped film, respectively. So, the 5.6 vol.% BHO-doped film exhibited higher performance. The maximum flux pinning force densities ($F_p^{MAX}$) were 779, 157 and 14.2 GN/$m^3$ at 20, 60 and 77 K, respectively. At high measurement temperature from 80 to 85 K, two peaks were observed in the $F_p$-$B$ curves of the 5.6 vol.% BHO film. We considered that these peaks might result in the flux pinning due to the BHO nano-rods and natural defects. On the contrary, at low measurement temperatures from 20 to 77 K, we observed only a single peak in the $F_p$-$B$ curves. We will discuss flux pinning properties in other samples and compare with the 5.6 vol.% BHO film.

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