# Polarization-Dependent Raman Scattering Spectroscopy of $Gd_{1+x}Ba_{2-x}Cu_3O_7$ Coated Conductors

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*Abstract*— **We made $Gd_{1+x}Ba_{2-x}Cu_3O_7$ (GdBCO) coated conductors on ion-beam assisted deposition MgO templates by pulsed laser deposition with different oxygen partial pressures. Structural properties of GdBCO coated conductors were investigated by Raman scattering spectroscopy. According to the Raman scattering Z(YY)Z' polarization geometry spectra of samples grown at 300 mTorr, peaks at 326 $cm^{-1}$, 447 $cm^{-1}$, and 503 $cm^{-1}$ were found and assigned to one $B_{1g}$ mode and two $A_{1g}$ modes, respectively. Topography of the surface is observed with no $BaCuO_2$ grains, which are common to other rare-earth based cuprates. Critical currents of the films were measured as about 90 A/cm (500 mTorr) and 60A/m (300 mTorr). The high-critical current behaviors of GdBCO are explained by the fact that they are grown as highly textured 123-phases with no second phases and cation exchange.**

## I. Introduction

$ReBa_2Cu_3O_{7-\delta}$ (ReBCO, Re = rare earth element) coated conductors have attracted great attention since they are known to possess strong flux pinning centers [1]. They show a good performance in high magnetic fields in terms of critical currents ($I_c$), and high critical temperatures ($T_c$). In general, good quality high temperature superconductors (HTS) require no cation disorder, enough oxygen contents, and biaxially grown textures. The features are related to growth conditions such as substrate temperature (Ts) and oxygen partial pressure ($PO_2$). Hence it is important to monitor process and growth by way of a proper analytical method. One of the HTS materials, $YBa_2Cu_3O_7$ (YBCO) films have been extensively discussed for in-situ growth conditions of various Ts and $PO_2$ [2]. According to the report, the YBCO films were made near the straight line which is called Hammond-Bormann line. This line is in a 1/T-log$PO_2$ plane. The other HTS materials like $Nd_{1+x}Ba_{2-x}Cu_3O_7$ (NdBCO) show the high critical temperature ($T_c \sim$ 96 K), mostly higher $J_c$ than YBCO in the magnetic field [3]. In early works of our group [4], we fabricated good quality NdBCO films on IBAD-YSZ templates via PLD. The NdBCO films that were grown at 765 ~785 ºC have 100% c-axis orientation. However, the films showed less cation disorder resulting in high $T_c$ and $J_c$ while they possessed a little Ba-Cu oxide phases from liquid [5].

Raman scattering spectroscopy is a spectroscopic tool which is broadly used in condensed matter physics and chemistry to study vibrational, rotational, and other low-frequency modes in a system. Raman scattering spectroscopy detects oxygen content which influence the superconducting properties [6]. Further, it can be use to find the cation-disorder, i.e., substituting $Gd^{3+}$ ions onto the $Ba^{2+}$ sites or mixing with two cations result in difference in Raman scattering spectra. In addition, the formation of Ba-Cu-O second phases during the growth leads to peculiar vibrational modes in the Raman scattering spectra, so that it is possible to trace back the processing records. In this paper, we fabricated GdBCO coated conductor on IBAD-MgO templates by PLD. We investigated the effect of oxygen partial pressure to growth and superconducting properties using Raman scattering spectroscopy.

## II. Experiments

The GdBCO coated conductors were deposited on MgO (100) substrates by a pulsed KrF excimer laser (LPX220i from Lambda Physik with 248 nm wavelength) with different oxygen partial pressures. The architecture of the substrates is $LaMnO_3$(150nm)/homo-epi MgO(100nm)/IBAD-MgO (10nm)/$Gd_2O_3$(7.5nm)/$Al_2O_3$(7.5nm) /Hastelloy. The thickness is about 500 nm. The chamber was evacuated to a base pressure of 5 x $10^{-6}$ Torr prior to the deposition. The energy density of the laser beam on the target surface (5 x 1 $mm^2$) was 2 $J/cm^2$. It takes 20 minutes for depositing on two coated conductors. Following previous work in our group, we used x-ray diffraction (XRD) for phase and crystalline analyses of the GdBCO films. XRD was measured as $\theta-2\theta$ scans by a four-circle goniometer. The Raman scattering spectra were measured in a quasi-backscattering geometry using 40mW of the 514.5 nm wavelength of an Ar ion laser. By Raman scattering spectra the crystal orientation of the coated conductors was investigated. In addition, we used atomic force microscopy (AFM) images to analyze the surface of the GdBCO coated conductors. It employs a contact mode using a silicon cantilever with Al coating on the detector side. The resistivity of cantilever is 0.01~0.02 Ωcm.

## III. Results and Discussion

Polarized Raman spectra taken at room temperature of the GdBCO coated conductors are shown in Fig. 1. We measured Raman scattering spectra using by quasi-backscattering geometry to investigate the phonon modes, second phases, and crystal orientation. The grating of the spectrometer used was 1200 grooves/mm and was optimized at 500nm. Polarization of the incident and scattered light were chosen as XX, XY, YX and YY. As in top of Fig. 1, XX present incident light with 0 degree and scattered light with 0 degree along with the template's moving direction. In the spectra, we can clearly assign two $A_{1g}$ modes and one $B_{1g}$ mode (in the orthorhombic phase) that are found in another ReBCO compounds. However, there was no observation of $E_g$ symmetry: non-diagonal in the tetragonal phase. In the sample grown at 300 mTorr, Raman shift peaks are observed at around 326 $cm^{-1}$, 447 $cm^{-1}$ and 503 $cm^{-1}$. The $B_{1g}$ mode at 326 $cm^{-1}$ is oxygen-oxygen out-of-phase bending in $CuO_2$ plane mode. The other two $A_{1g}$ modes at 447 $cm^{-1}$ and 503 $cm^{-1}$ are oxygen-oxygen in-phase in $CuO_2$ plane mode and O4 apical oxygen mode, respectively. The peak near 500 $cm^{-1}$ is well known the Cu-O axial stretch mode. This feature of the $A_{1g}$ mode is decreased with increasing oxygen deficiency [7]. The two smaller $A_{1g}$ modes found around 230 $cm^{-1}$ and 605 $cm^{-1}$ correspond to stretching vibrations of copper and oxygen atoms, respectively [8]. In the 500 mTorr-grown GdBCO sample, the peaks from the one $B_{1g}$ mode and two $A_{1g}$ modes are shifted by +3 and -3 $cm^{-1}$, respectively. In the XY and YX polarization geometry, Raman spectra do not show the $B_{1g}$ mode in both of the GdBCO coated conductor. An appearance of the $O_p$ $B_{1g}$ near 315 $cm^{-1}$ mode of ReBCO Raman spectra are determined by the direction of the film growth. A c-axis oriented film shows a strong peak in the parallel polarization to the c-axis [4]. Therefore we confirmed by polarization-dependent Raman scattering spectroscopy that the two coated conductors were grown in the c-axis orientation. As was reported for NdBCO [4], for films grown at 775 and 785 ºC, the Raman shift peaks appear around ~ 600 and 630 $cm^{-1}$, which are ascribed to Ba-Cu-O phase[9], indicating that the NdBCO phases form during liquid-phase assisted growth. As in the previous report of H. J. Rosen [10], in the YBCO samples, even small concentrations of impurity phases can strongly influence the Raman spectra. Since the impurity phases are less absorbing than superconducting phases. So it can have large cross section [10]. However in our GdBCO data, we cannot observe outstanding peaks above 600 $cm^{-1}$. It could be one of the evidences about no secondary phases.

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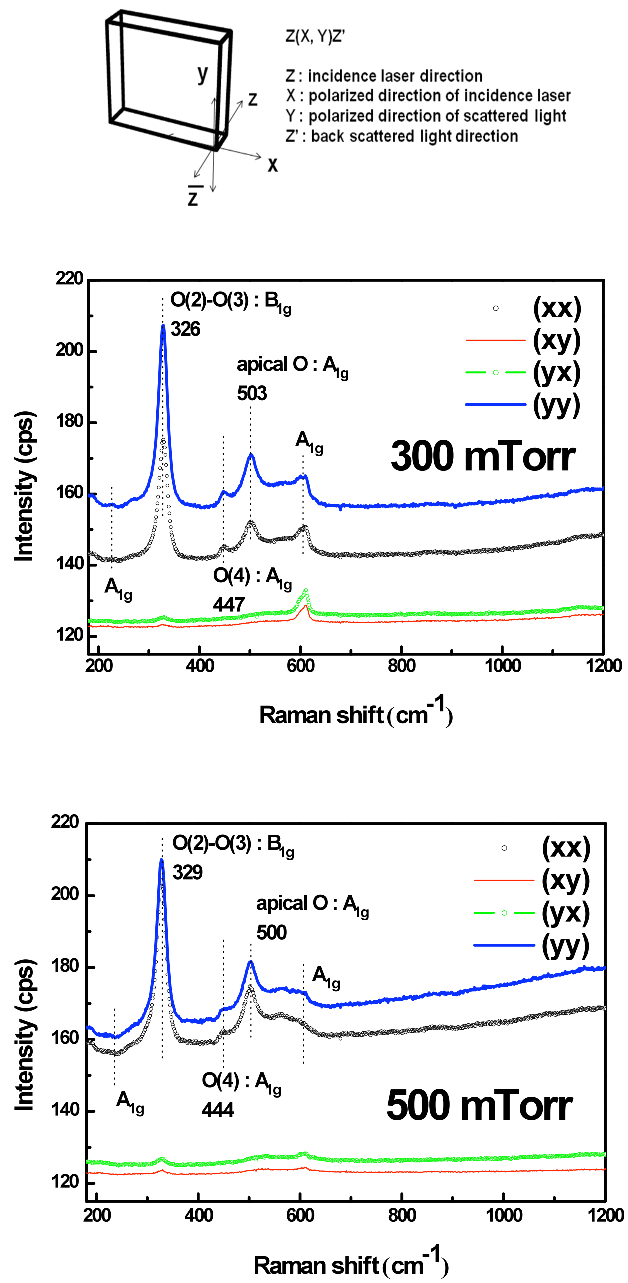


Fig. 1. Raman scattering spectroscopy of the GdBCO coated conductors has grown at PO2 = 300 mTorr and 500 mTorr. The spectral range of the measurement is from 180 to 1200 cm-1. The spectra show phonon modes at 326, 447, and 503 cm-1 for the 300 mTorr-grown sample while for the sample that was grown at 500 mTorr gives at 329, 444, and 500 cm-1.