Carbon substitution effect in MgB$_2$

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We investigated carbon substitution effect on boron plane of superconducting MgB$_2$. MgB$_2$ and MgB$_{1.8}$C$_{0.2}$ samples are synthesized under high pressure furnace. MgB$_{1.8}$C$_{0.2}$ are characterized as AlB$_2$-type single phase with smaller B-B distance. During the superconducting transition, two distinct onset temperatures are observed in MgB$_{1.8}$C$_{0.2}$.

Since the discovery of superconducting property in MgB$_2$ by Akimitsu et al. [1], much efforts are spent on understanding the type of carriers and the way of optimization with chemical substitution. As far as we know, chemical substitution of elements are focused mostly on magnesium substitution with chemical substitution. As far as we know, chemical substitution of elements are focused mostly on magnesium substitution. Mg-site surrounded by neighboring 12 boron cages, with an exception of $^{10}$B isotope effect by Bud’ko et al. [3].

Several alkali and alkali earth and group III elements are used as getters inside the furnace. Mg (99.8%, Alfa), amorphous B (99.99%, Alfa), and carbon (99.9%, Acros) are used as getters inside the furnace. Some amounts of magnesium turnings ($^{2}$H$_2$) and MgB$_2$ are used as internal standards. (Parameters are also calculated for MgB$_{1.8}$C$_{0.2}$: $a_H = 3.070$ Å and $c_H = 3.520$ Å. From these results, we notice that only $a_H$ (B-B distance) decreases and $c_H$ (separation between B planes) is not varied with carbon substitution. This is more clear from Fig. 1(b), showing the movement of (100), (101), and (002) lines with carbon substitution.

Comparison with the result of other elements is intriguing at this point. In Al$^{3+}$-substitution (hole doping), both a- and c-axis length decrease with doping, and the change in c-axis is significant at high doping limits ($\geq 0.25$ Al). For Be$^{2+}$-substitution (no doping, ion size effect), it is well-known that Be cannot dope Mg site because it forms stable phase of BeB$_2$. And in Li$^+$-substitution (electron doping), c-axis does not vary and a-axis length decreases with doping concentration ($\leq 0.3$ Li). C$^{4+}$ is quite similar to our result: C$^{4+}$ ion is smaller than B$^{3+}$ and electron doping is expected from ionic picture.

In order to see the changes in superconducting properties, dc resistivity is measured on a closed-cycle He refrigerator (Janis, CCS350), with a standard four-point probe technique with polished rectangular sample of dimension $\sim 2 \times 5 \times 1$ mm$^3$, where electrical contact is made with silver epoxy (Dotite) and thermal one with grease (Apiezon, N). Figure 2 shows the sample resistivities normalized with the values at 50 K and inset shows the region of phase transition. Normal state resistivity level of MgB$_2$ and MgB$_{1.8}$C$_{0.2}$ is different by two orders of magnitude, such as $\rho(50K) = 93 \, \mu \Omega cm$ (MgB$_2$) and 19 n$\Omega cm$ (MgB$_{1.8}$C$_{0.2}$), partly due to the low density of our MgB$_{1.8}$C$_{0.2}$ pellet. However, their normal state power-law dependence ($\rho \sim a + bT^n$) and residual resistivity ratio ($\rho(T_c^+)/\rho(300K) \sim 0.55$) are quite similar. In MgB$_2$, the resistivity drops at 38.8 K and the transition is completed within 1 K, as shown in the inset, which is quite close to the report of Akimitsu et al. [1]
Compared with MgB$_2$, the transition width is very broad ($\sim 8$ K) in MgB$_{1.8}C_{0.2}$, which begins at 41 K and ends at 33 K. Also, the resistivity shows two distinct onset temperatures indicated with $\nabla$ symbols in the inset ($T_c1 \sim 41$ K and $T_c2 \sim 37$ K). Considering the single group of AlB$_2$-type patterns of x-ray, structural inhomogeneity may not be related with this observation, however, some intergrain effect should be counted. According to our preliminary results of different doping concentrations, structural segregation begins at some higher doping and MgB$_{1.8}C_{0.2}$ is near optimum in its property. Because carbon substitution gives influences in effective mass and charge valency of undoped boron planes, we speculate some changes in phonon or electronic structure corresponding to this carbon substitution. In this respect, further progresses with boron plane substitution are anticipated.

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FIG. 1. (a) X-ray $\theta$-2$\theta$ diffraction patterns(Cu K$_{\alpha}$) of MgB$_2$ and MgB$_{1.8}C_{0.2}$ powders. (b) Enlarged patterns in the region of the (100), (101), and (002) reflections. MgO impurities are shown with asterisks.

FIG. 2. Dc resistivities normaled at 50 K ($\rho(T)/\rho(50K)$) of MgB$_2$ and MgB$_{1.8}C_{0.2}$. Inset shows the region of the transition temperatures.
Fig. 1 of Ahn and Choi
Fig. 2 of Ahn and Choi