Superconductivity of Mg\((B_{1-x}C_x)_{2}\) ternary compounds

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The structural properties and superconductivity of Mg\((B_{1-x}C_x)_{2}\) compounds were investigated by means of powder x-ray diffraction (XRD) and magnetization measurements. Powder XRD Rietveld analysis indicates that the samples crystallize in a hexagonal AlB\(_2\)-type structure. The lattice parameter \(a\) decreases slightly with increasing carbon content, while \(c\) remains unchanged. The addition of carbon results in a decrease of \(T_C\) and an increase in the superconducting transition width, while the critical current density \(J_c\) data indicate that MgB\(_{1.8}\)C\(_{0.2}\) manifests comparable superconducting properties with MgB\(_2\). © 2002 American Institute of Physics. [DOI: 10.1063/1.1456422]

I. INTRODUCTION

The discovery of superconductivity at about 39 K in magnesium diboride has resulted in a renaissance of interest in intermetallic superconductivity.\(^1\)–\(^3\) This discovery in a simple compound with relatively high superconducting transition temperature may open a new route towards the search of high temperature superconductors. In order to investigate the effect of electron concentration on \(T_C\), Slusky et al. have synthesized the solid solutions of Mg\(_{1-x}\)Al\(_x\)B\(_2\) and investigated its structural transition and superconductivity.\(^4\) It was found that the superconducting transition temperature decreases with increasing Al concentrations, and the superconductivity disappears with \(x>0.4\). In this work, the critical current density and critical field of Mg\((B_{1-x}C_x)_{2}\) ternary compounds were investigated.

II. EXPERIMENT

The samples were prepared from powdered magnesium (98.5\% in purity), B (99.99\% in purity), and C (99.99\% in purity) powders. The powders were well mixed in an appropriate ratio, and pressed into pellets. The pellets were sealed in a quartz tube and sintered at 950 K for 2 h. The phase purity of Mg\((B_{1-x}C_x)_{2}\) was checked by x-ray diffraction (XRD) patterns. Powder XRD patterns were collected by an x-ray spectrometer with Cu \(K_a\) radiation over a 2\(\theta\) from 20\(^{\circ}\) to 80\(^{\circ}\) with a step of 0.02\(^{\circ}\). The structural properties were determined by Rietveld profile refinement. The temperature dependence of magnetization of the samples was measured by a superconducting quantum interference device (SQUID) magnetometer in an applied field of 20 Oe. The M-H loops were measured in a magnetic field ranging from -50 to 50 kOe at different temperatures by means of the SQUID magnetometer. In order to calculate the critical current density \(J_c\), the sample has been cut with a diamond saw into a rectangular shape with size 2.87 mm (length) \(\times\) 2.70 mm (width) \(\times\) 3.12 mm (thickness).

III. RESULTS AND DISCUSSION

XRD patterns indicate that the main diffraction peaks can be indexed with a hexagonal structure of Mg\((B_{1-x}C_x)_{2}\).

A small amount of impurity phase MgO was detected due to the chemical activity of Mg powders. The XRD patterns can best fitted with these two phases. For example, Fig. 1 illustrates the observed and fitted XRD patterns of MgB\(_2\) and MgB\(_{1.8}\)C\(_{0.2}\). In the hexagonal structure (space group \(P6/mmm\)), Mg atoms occupy the 1\(a\) site (0,0,0), and B atoms locate at the 2\(d\) (1/3,2/3,1/2) site. The Rietveld fitting result demonstrates that carbon atoms preferentially occupy the 2\(d\) site. The crystal structure of AlB\(_2\)-type compounds

![Fig. 1. Cu \(K_a\) powder x-ray diffraction pattern of Mg\((B_{1-x}C_x)_{2}\) with \(x = 0.0\) and 0.1. The observed data and fitted patterns are indicated by closed circles and solid lines, respectively. The lowest curves are the difference between observed and calculated patterns. The vertical bars indicate the expected reflection peaks’ positions.](image-url)
consists, therefore, of alternating hexagonal layers of Mg atoms and graphitelike honeycomb layers of B and C atoms. The lattice parameters, \( a \) decreases from 3.086 to 3.070 Å, implying that carbon atoms enter into MgB\(_2\) phase, while \( c = 3.524 \) Å remains unchanged.

Figure 2 illustrates the temperature dependence of magnetization of Mg(B\(_{1-x}\)C\(_x\))\(_2\) intermetallic compounds. The samples were cooled to 5 K in zero field cooling (ZFC), and then measured in a magnetic field of 20 Oe from 5 to 50 K. It is noteworthy that the superconducting transition is both relatively high and sharp in the MgB\(_2\) compound. With increasing carbon content, the temperature dependence curves become less sharp. The superconducting transition temperature determined from the onset temperature of 2% of the full diamagnetic signal at low temperature was found to decrease from about 39 K for \( x = 0.00 \) to 34 K for \( x = 0.20 \). The superconducting transition width for a 10% to 90% drop, \( \Delta T_C \), increases from 1 to 3 K with introducing carbon atoms. The decrease of \( T_C \) for the Mg(B\(_{1-x}\)C\(_x\))\(_2\) system can be attributed to a reduction in the density of states at the Fermi level, as predicted by band structure calculations.\(^5\)

Figure 3 shows a plot of magnetization versus applied field at various temperatures in the ZFC state. The initial deviation of the magnetization from linearity, corresponding to a lower critical field, is only few hundred Oe, and decreases with increasing temperature. In order to calculate the critical current density, the magnetization hysteresis loops (MHLS) were measured at different temperatures. As illustrated in Fig. 4(a), all curves show a symmetric behavior indicating the importance of bulk current instead of surface shielding current. From these MHLS one can calculate \( J_C \) via \( J_C = \frac{20 \Delta M}{V a (1 - a/3b)} \) on the basis of the Bean critical state model, where \( \Delta M \) is the width of the MHL, and \( V, a, \) and \( b \) are the volume, length, and width of the sample, respectively.\(^6\) The result of \( J_C \) is illustrated in Fig. 4(b). It is clear that the bulk critical current of our sample is rather high. The current density of Mg(B\(_{1-x}\)C\(_x\))\(_2\) samples has the same order of magnitude as that of MgB\(_2\) (10\(^5\) A/cm\(^2\)).\(^7-9\)

IV. SUMMARY

The structural properties and superconductivity of Mg(B\(_{1-x}\)C\(_x\))\(_2\) were investigated by means of powder x-ray diffraction patterns and magnetization measurement. It was found that carbon atoms preferably occupy B layers. With the introduction of smaller carbon atoms, the atomic distance in the B layer decreases slightly, while the interlayer between
the B and Mg distance remains unchanged. The addition of carbon leads to a decrease in the superconducting transition temperature, while the critical current density and critical field is comparable with the MgB$_2$ compound.

ACKNOWLEDGMENTS

This work was supported by the National Natural Sciences foundation of China and the State Key Project of fundamental research, China. The authors would like to thank Rui-wei Li and Tai-shan Ning for their kind help in sample preparation and x-ray diffraction measurements.