Pressure Dependence of BaNi$_2$As$_2$

T. Park$^1$, H. Lee$^2$, E.D. Bauer$^2$, J.D. Thompson$^2$, F. Ronning$^2$

$^1$Department of Physics, Sungkyunkwan University, Suwon 440-746, Korea
$^2$Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

E-mail: fronning@lanl.gov

Abstract. We report resistivity measurements of BaNi$_2$As$_2$ up to pressures of 27.4 kbar. We find the structural transition at 130 K is broadened slightly with increasing pressure. There is also minimal influence on the superconducting transition, where the resistive onset increases from 2 to 3 K, but the temperature at which zero resistance is obtained is unchanged up to 27.4 kbar. This behavior is in contrast to that observed in the Fe-based systems as well as in LaNiPO and LaNiAsO.

1. Introduction

Following the discovery of superconductivity at 26 K in LaFeAs(O,F)$^1$ many new superconductors were discovered which possessed the same fundamental building block of puckered T$_2$Pn$_2$ planes (T=Transition metal, Pn=Pnictide element). Most attention has focused on compounds with Fe$_2$As$_2$ planes which not only have the highest transition temperatures, but also are in close proximity to magnetism, therefore suggesting some similarity to the high T$_c$ cuprates.

However, many Ni-based $^{[2-14]}$ and several other non-Fe-based$^{[15; 16]}$ superconductors have also been discovered. The transition temperature of these compounds has yet to exceed 5 K, and to date there is no evidence for proximity to an antiferromagnetic ground state$^{[17]}$. Thermal conductivity measurements of BaNi$_2$As$_2$ reveal that the system is a fully gapped superconductor$^{[18]}$; consequently, the more complex Fermi surfaces of the Ni-compounds$^{[19]}$ relative to the Fe-analogs suggest that BaNi$_2$As$_2$ is a conventional BCS superconductor. This is supported by phonon calculations which can account for the magnitude of T$_c$ within a conventional electron-phonon coupling framework$^{[19]}$. As this is not possible for the FeAs compounds it further suggests that there is no relation, other than structural similarity, between the Fe-based and non-Fe-based T$_2$Pn$_2$ superconductors. However, the trend of the superconducting transition temperature in doped LaTAsO is similar$^{[17]}$ for T=Fe$^{[1; 20]}$ and T=Ni$^{[8; 9]}$. In addition, the trend in T$_c$ across several families of compounds is similar for both Fe and Ni compounds$^{[11]}$. The origin for these two similarities is unknown and thus leaves open the possibility that the mechanism of the Fe-based and Ni- (and other non-Fe-) based compounds are related. Thus, one is motivated to continue studying the non-Fe-based superconductors either because they are simply good non-magnetic reference compounds for comparing to the Fe-based systems or because they may provide an alternative route for unraveling the mechanism of superconductivity due to the fact that their pairing is not as well optimized as it is in the Fe-based systems.

© 2010 IOP Publishing Ltd
In this work we report on the pressure dependence of the structural and superconducting transition temperatures of BaNi$_2$As$_2$ up to 27.4 kbar. At ambient pressure BaNi$_2$As$_2$ possesses a structural transition at 130 K and becomes superconducting at a transition temperature of 0.7 K\cite{6}. Theoretical work has argued that the structural transition is an electronically driven structural transition\cite{21}. We find that with increasing pressure the structural transition is slightly broadened, while there is negligible influence on the superconducting transition.

2. Experimental
Single crystals of BaNi$_2$As$_2$ were synthesized as reported in ref. \cite{6}. A crystal was mounted inside a Teflon cup within a hybrid BeCu/NiCrAl clamp-type pressure cell. Silicon oil was used as the pressure transmitting medium, and a small piece of Pb whose known pressure-dependent superconducting transition enabled a determination of the pressure within the cell\cite{22}. A standard 4 point setup with spot welded contacts was used to measure resistivity.

3. Results
With applied pressure the sharp first order structural transition is progressively broadened with increasing pressure, as shown in figure 1. Similar behavior occurs in CaFe$_2$As$_2$ [23; 24] and is believed to result from the fact that the pressure transmitting medium while liquid at room temperature, freezes before the structural transition of the material being studied. Consequently, there is a slight nonhydrostatic environment (< 0.01 GPa) nucleating structural inhomogeneity which induces further strain on the crystal allowing for a broadened transition and possibly even a structurally composite phase at low temperature. The pressure dependence of the transition and its width for BaNi$_2$As$_2$ is presented in figure 2.

**Figure 1.** Resistivity versus temperature of BaNi$_2$As$_2$. With increasing applied pressure the transition broadens. The inset shows the low temperature resistivity at ambient pressure and 27.4 kbar, with a superconducting onset temperature of 2 K and 3 K respectively. The temperature at which zero resistance occurs does not change.

**Figure 2.** Pressure dependence of the structural and superconducting transitions from resistivity data. Squares indicate the lowest temperature to which measurements were made.

At ambient pressure the onset of superconductivity is observed by resistivity at 1.94 K, despite a bulk superconducting transition as observed by heat capacity occurring at 0.68 K\cite{6}.
The origin of this onset transition is unknown, and is observed in crystals grown both in Pb flux and NiAs flux [25]. By applying pressure we observe this onset to monotonically increase with increasing pressure up to 3.06 K at 27.4 kbar, the maximum pressure studied. On the other hand, the zero resistance state correlates much better with the heat capacity anomaly at ambient pressure. Data were measured below 1.8 K only at ambient pressure and at 27.4 kbar, for which the temperature at which zero resistance occurred was unchanged as can be seen in figure 1. While we can not rule out a pressure dependence to the bulk transition, it seems unlikely that significant variation occurs given the fixed endpoints at 1 bar and 27.4 kbar and the slow monotonic increase to the resistive onset. This is in contrast to the behavior in LaNiXO (X=As, P), which demonstrates a dome of superconductivity with applied pressure[26] similar to the Fe-analog LaFeAs(O,F)[27]. Perhaps larger pressures are required to observe similar behavior as is the case for BaFe$_2$AS$_2$[28; 29]. In SrNi$_2$P$_2$ $T_c$, which is 1.4 K at ambient pressure, is monotonically suppressed with increasing pressure[11].

4. Conclusions
In conclusion, we have measured the pressure dependence of the structural as well as superconducting transition in BaNi$_2$As$_2$ up to 27.4 kbar. In contrast to LaFeAsO, LaNiAsO, and LaNiPO, we find very little pressure dependence on either the structural or superconducting phase transitions.

Acknowledgments
TP acknowledges a support by KOSEF grant (R2009-0058687) funded by the Korean government (MEST). Work at Los Alamos was performed under the auspices of the United States Department of Energy.

References
[1] Kamihara Y, Watanabe T, Hirano M and Hosono H 2008 Journal of the American Chemical Society 130 3296–3297
[2] Watanabe T, Yanagi H, Kamiya T, Kamihara Y, Hiramatsu H, Hirano M and Hosono H 2007 Inorganic Chemistry 46 7719–7721
[3] Tegel M, Bichler D and Johrendt D 2008 Solid State Sciences 10 193 – 197 ISSN 1293-2558
[4] Klimczuk T, McQueen T M, Williams A J, Huang Q, Ronning F, Bauer E D, Thompson J D, Green M A and Cava R J 2009 Physical Review B (Condensed Matter and Materials Physics) 79 012505 (pages 4)
[5] Mine T, Yanagi H, Kamiya T, Kamihara Y, Hirano M and Hosono H 2008 Solid State Communications 147 111 – 113 ISSN 0038-1098
[6] Ronning F, Kurita N, Bauer E D, Scott B L, Park T, Klimczuk T, Movshovich R and Thompson J D 2008 Journal of Physics: Condensed Matter 20 342203 (4pp)
[7] Watanabe T, Yanagi H, Kamihara Y, Kamiya T, Hirano M and Hosono H 2008 Journal of Solid State Chemistry 181 2117 – 2120 ISSN 0022-4596
[8] Li Z, Chen G, Dong J, Li G, Hu W, Wu D, Su S, Zheng P, Xiang T, Wang N and Luo J 2008 Physical Review B (Condensed Matter and Materials Physics) 78 060504 (pages 4)
[9] Fang L, Yang H, Cheng P, Zhu X, Mu G and Wen H H 2008 Physical Review B (Condensed Matter and Materials Physics) 78 104528
[10] Bauer E D, Ronning F, Scott B L and Thompson J D 2008 Physical Review B (Condensed Matter and Materials Physics) 78 172504 (pages 3)
[11] Ronning F, Bauer E D, Park T, Baek S H, Sakai H and Thompson J D 2009 Physical Review B (Condensed Matter and Materials Physics) 79 134507 (pages 7)
[12] Kozhevnikov V L, Leonidova O N, Ivanovskii A L, Shein I R, Goshchitskii B N and Karkin A E 2008 JETP letters) 87 649
[13] Fujii H and Kasahara S 2008 Journal of Physics: Condensed Matter 20 075202 (5pp)
[14] Matsumura Y, Ogino H, Horii S, Katsura Y, Kishio K and ichi Shimoyama J 2009 Applied Physics Express 2 063007
[15] Jeitschko W, Glaum R and Boon L 1987 Journal of Solid State Chemistry 69 93 – 100
[16] Hirai D, Takayama T, Higashinaka R, Aruga-Katori H and Takagi H 2009 Journal of the Physical Society of Japan 78 023706
[17] Ronning F, Bauer E, Park T, Kurita N, Klimeczuk T, Movshovich R, Sefat A, Mandrus D and Thompson J 2009 Physica C: Superconductivity 469 396 – 403 ISSN 0921-4534
[18] Kurita N, Ronning F, Tokiwa Y, Bauer E D, Subedi A, Singh D J, Thompson J D and Movshovich R 2009 Physical Review Letters 102 147004 (pages 4)
[19] Subedi A and Singh D J 2008 Physical Review B (Condensed Matter and Materials Physics) 78 132511 (pages 4)
[20] Wen H H, Mu G, Fang L, Yang H and Zhu X 2008 EPL (Europhysics Letters) 82 17009 (5pp)
[21] Chen Z G, Xu G, Hu W Z, Zhang X D, Zheng P, Chen G F, Luo J L, Fang Z and Wang N L 2009 URL http://arXiv.org:0905.0841
[22] Eiling A and Schilling J S 1981 Journal of Physics F: Metal Physics 11 623–639
[23] Park T, Park E, Lee H, Klimeczuk T, Bauer E D, Ronning F and Thompson J D 2008 Journal of Physics: Condensed Matter 20 322204 (3pp)
[24] Torikachvili M S, Bud’ko S L, Ni N and Canfield P C 2008 Physical Review Letters 101 057006 (pages 4)
[25] Sefat A S, McGuire M A, Jin R, Sales B C, Mandrus D, Ronning F, Bauer E D and Mozharivskyj Y 2009 Physical Review B (Condensed Matter and Materials Physics) 79 094508 (pages 8)
[26] Okada H, Takahashi Y, Igawa K, Ariii K, Takahashi H, Watanabe T, Yanagi H, Kamihara Y, Kamiya T, Hirano M, Hosono H, Nakano S and Kikegawa T 2008 Journal of the Physical Society of Japan 77SC 119–120
[27] Takahashi H, Igawa K, Ariii K, Kamihara Y, Hirano M and Hosono H 2008 Journal of the American Chemical Society 453 376–378
[28] Alireza P L, Ko Y T C, Gillett J, Petrone C M, Cole J M, Longarich G G and Sebastian S E 2009 Journal of Physics: Condensed Matter 21 012208 (4pp)
[29] Fukazawa H, Takeshita N, Yamazaki T, Kondo K, Hirayama K, Kohori Y, Miyazawa K, Kito H, Eisaki H and Iyo A 2008 Journal of the Physical Society of Japan 77 105004