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Research articles

Magnetic correlations and transport properties in triangular-lattice nickel germanide $Ni_{1.8}Ge$ single crystal

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ABSTRACT

Magnetic and transport properties of triangular-lattice $Ni_{1.8}Ge$ single crystal have been studied. The results reveal that $Ni_{1.8}Ge$ is a metal with an obvious magnetic anisotropy. The compound exhibits ferrimagnetic correlations along both directions. However, the long-range magnetic order was not observed due to the geometrical frustration arising from the triangular nickel lattice. At low temperature, the electron-magnon scattering and spin fluctuation have obvious contributions to the resistivity and magnetoresistance, indicating the existence of short-range dynamic magnetic ordering.

1. Introduction

Frustration is prevalent in condensed matter physics and often leads to the novel properties, such as spin liquid [1–7], spin ice [2,4,8–10], quantum or topological anomalous Hall effect [2,11–14], large electron–electron interactions [15,16] and quantum criticality [4,17,18]. Systems with frustration have degenerate ground states because of competing interactions with comparable strengths [19–21]. Spin frustration may occur in antiferromagnets consisting of triangular motifs for instance, physically refer to competition between all of pairwise antiparallel spin that cannot be simultaneously satisfied [2,4]. Consequently, the exotic physical properties are often observed in the magnetic materials with triangular lattice. For example, the topological anomalous Hall effect was presented in triangular lattice antiferromagnetic $PdCrO_2$ due to the geometrically frustrated lattice structure [52]. In triangular itinerant ferromagnet Fe_3GeTe_2, anisotropic anomalous Hall effect with different mechanisms was attributed to the noncoplanar spin textures arised from the frustrated lattice structure [23]. For the triangular lattice antiferromagnetic Cs_2CuCl_4, owing to the frustrated lattice structure, the quantum spin liquid state was observed, which leads to the spinons [4]. These make the magnetic materials with triangular lattice good systems to search for the novel properties.

Intermetallic compounds of nickel germanides (Ni_xGe) have been considered as one of potential basic materials for electronic devices [24,25], because Ge can provide higher and more symmetric low-field carrier mobility than Si, which may improve channel carrier mobility [26]. These compounds also share similar lattice structures and have close parameters with nickel silicide compounds which are popular for the application in the file of electronics [27], such as serving as a electrical contact layer to overcome the limitation of Schottky barrier presence in Si-based devices. Owing to low resistivity and good thermo-kinetic quality, nickel germanides have also been studied as one of the favored contact materials in complementary metal-oxide semiconductor devices [28,29]. In addition, Ni_3Ge exhibits ferromagnetism above room temperature, which may offer advantages over silicides for potential applications in spintronics [30]. Therefore, it is of great interest to clarify the roles that Ni-Ge compounds can play for applied prospects. Ni_xGe alloys have a complex phase diagram, in which there is a broad homogeneity range between $1.5 \leqslant x \leqslant 2$ [30–33]. In this solid solution region, Ni_xGe ($1.5 \leqslant x \leqslant 2$) has a NiAs-type crystal structure, in which Ni atoms with two different Wyckoff positions form the triangular lattices. However, excepting the crystal structure and phase diagram [30–37], less work has been done on these compounds to understand the magnetic and transport properties. $Ni_{1.8}Ge$, which is located in the middle of the homogeneous solution region [30–33], is expected to be a composition with pure

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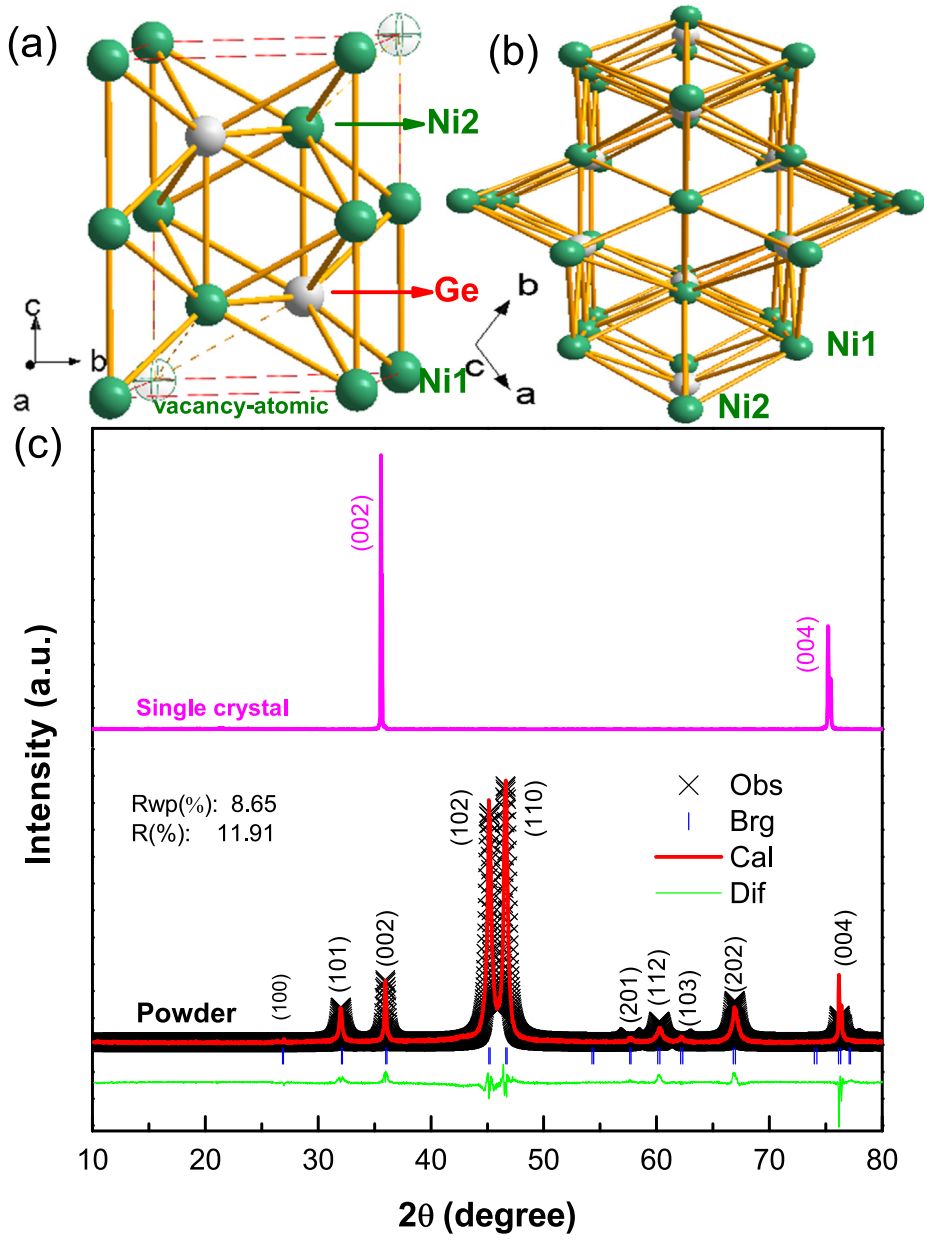

Fig. 1. (a) The crystal structure of $Ni_{1.8}Ge$. (b) The triangular lattices of Ni atoms. (c) The single-crystal and powder XRD patterns of $Ni_{1.8}Ge$. The solid red line shows the calculated result of the Rietveld refinement, the vertical blue bars show the theoretical Bragg peak positions and the green line shows the difference between the observed and calculated data. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Parameters obtained from the calculated results of the Rietveld refinement.

Space group	$P6_3/mmc$
Lattice parameters	$a = b$=3.95Å, c = 5.05Å
Rwp(%)	8.65
R(%)	11.91

and stable phase. Thus, the study on $Ni_{1.8}Ge$ will reveal the intrinsic physical properties and help us to understand other compounds in this solution area.

Motivated by the above reasons, we studied magnetic and transport properties of $Ni_{1.8}Ge$ single crystals with nickel triangular lattice. The results imply that $Ni_{1.8}Ge$ is a metal with ferrimagnetic correlations. The low temperature resistivity and MR also reveal a strong electron-magnon scattering contribution from the short-range dynamic magnetic order. The absence of long-range magnetic order may be due to the geometrical frustration of nickel lattice.

2. Experimental details

Plate-like single crystals of $Ni_{1.8}Ge$ were synthesized by chemical vapor transport method by using iodine as a transport agent. The lattice parameters were checked by X-ray diffraction (XRD) on a Rigaku-TTR3 X-ray diffractometer by Cu K_α radiation with Bragg–Brentano geometry at room temperature. The energy dispersive X-ray spectroscopy (EDX) for chemical analysis was performed on an Oxford SWIFT3000 spectroscopy. Transport measurements were performed by using standard DC four-leads method on an