外国語要約

Candidate for ferromagnetic superconductor RET_2B_2C

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Superconductivity and ferromagnetism were initially considered to be mutually exclusive states of matter. However after Ginzburg predicted coexistence of these two states theoretically this topic has been revisited in great detail. Additional theoretical works suggested that such a coexistence state can be realized when an internal magnetic field, H_{int}, generated by the ferromagnetic state is weak enough not to destroy superconducting state. In addition, for the type-II superconductors a realization of a spontaneous vortex phase was predicted under the condition that the H_{int} satisfies the inequality $H_{c1} < H_{int} < H_{c2}$. Here H_{c1} and H_{c2} are the lower and the upper critical fields of superconductors, respectively. A series of RET_2B_2C (RE = Y and rare earth and T = transition metal) was discovered after 1994. The members host a variety of magnetic and superconducting phases, and the systems with RE = Tm, Er, Ho, Dy show coexistence between superconductivity and magnetic orders. Among them $ErNi_2B_2C$ (T_c = 10.5 K) became the first material to show a microscopic *stable* coexistence state between weak ferromagnetism and superconductivity below its weak ferromagnetic transition temperature, T_{WFM} = 2.3 K. However a spontaneous vortex phase has not been unambiguously confirmed due to the difficulty in generating a single magnetic domain without applying a magnetic field while the system being superconducting state, and so that it is not possible to exclude chance that observed vortices originated from flux pinning. To duly confirm an existence of spontaneous vortex phase, a system with $T_{WFM} < T_c$ is preferred. We choose $Tb_xY_{1-x}Ni_2B_2C$ as a candidate system. Here, $TbNi_2B_2C$ shows anti-ferromagnetic and weak ferromagnetic transitions at T_N = 15 K and T_{WFM} = 8 K but no superconductivity had been detected. On the other hand, YNi_2B_2C is a non-magnetic with a relatively high T_c = 15.7 K. B. K. Cho *et al*. studied a phase diagram of $Tb_xY_{1-x}Ni_2B_2C$ and reported that the system with x = 0.4 shows anti-ferromagnetic, superconducting and weak ferromagnetic transitions with $T_{WFM} < T_c < T_N$ and a sudden drop of T_c occurs at $x \sim 0.4$. These results indicate that there appears a system with $T_c < T_{WFM} < T_N$ in a vicinity of $x \sim 0.4$. To investigate this possibility, we grew a single crystal of $Tb_{0.47}Y_{0.53}Ni_2B_2C$ and performed detailed magnetization measurements. Then it was found that the system with x = 0.47 shows anti-ferromagnetic, weak ferromagnetic and superconducting transitions with decreasing temperature. Zero resistivity regarding superconductivity was observed by resistivity measurements. Anti-ferromagnetic, weak ferromagnetic and superconducting transition temperatures on $Tb_{0.47}Y_{0.53}Ni_2B_2C$ are determined as T_N = 7.0 K, T_{WFM} = 4.0 K and T_c = 2.2 K in zero field by the magnetization measurements.

In the present study, to confirm a realization of spontaneous vortex state and coexistence state between superconductivity and weak ferromagnetism and determination of magnetic structure in $Tb_{0.47}Y_{0.53}Ni_2B_2C$, we performed neutron scattering, magnetization, resistivity and magnetostriction measurements.

First, in order to confirm the presence of the weak ferromagnetic order magnetization measurements and polarized neutron diffraction measurements were performed. The magnetization data show that ferromagnetic moments grows below 4.0 K even under zero magnetic field and the magnetic moment is 0.9 μ_B/Tb at lowest temperature T = 0.48 K. On the other hands, temperature dependences of the intensities of polarized neutron diffraction at nuclear Bragg points (0 0 2) and (0 0 6) were measured. The intensities at both Bragg points show a distinct changes below

T_{WFM}, proofing weak ferromagnetic behavior detected in the magnetization measurements originated in $Tb_{0.47}Y_{0.53}Ni_2B_2C$.

For determination of anti-ferromagnetic structure on $Tb_{0.47}Y_{0.53}Ni_2B_2C$ unpolarized neutron diffraction experiments were performed. The results show that clear magnetic Bragg peaks develop below T_N at (0.56 0 0) and (0.44 0 1), indicating that magnetic moments on Tb atoms form a transverse spin density wave with a propagation vector $\boldsymbol{q} = 0.56\boldsymbol{a}^*$. It was revealed by magnetic moment analysis that magnetic moment of spin density wave is 6.84 μ_B/Tb at lowest temperature of 0.85 K. The magnetic field dependence of the magnetic Bragg peaks were also measured with magnetic fields parallel to ***a*** and ***b***. The magnetic Bragg peak at (0.56 0 0) disappeared when an external magnetic field H = 0.5 T was applied along ***a*** direction. Under the expectation of spin rotation and/or magnetic domain change, its magnetostriction was also measured. We confirmed the change of the domain ratio with increasing and decreasing external magnetic fields.

We have not reached an observation of the spontaneous vortex in $Tb_{0.47}Y_{0.53}Ni_2B_2C$, however, coexistence of superconductivity and weak ferromagnetism were confirmed and its anti-ferromagnetic structure was determined in zero magnetic field. Furthermore we performed field dependence measurements and succeeded in confirming the change of the magnetic domain ratio with increasing and decreasing magnetic field.