# Observation of Vortex Pinning in $YNi_2B_2C$ by LT-STS

Hideaki Sakata [a,1], Morimi Oosawa [b], Nobuhiko Nishida [b], Hiroyuki Takeya [c]
Kazuto Hirata [c]

[a] *Tokyo University of Science, Kagurazaka, Tokyo 162-8601, Japan*
[b] *Tokyo Institute of Technology, Ookayama, Tokyo 152-8551, Japan*
[c] *National Institute for materials Science, Sengen, Ibaraki 305-0047, Japan*

**Abstract**

The scanning tunneling spectroscopy measurements have been performed on the cut or cracked surface of $YNi_2B_2C$ at 4.2K in magnetic fields. The map of the quasiparticle density of states at the Fermi energy has revealed the vortex cores and the semiconducting precipitates. When the applied magnetic field is increased at 4.2K, the enhancement of the local density of states has been observed along the boundary of the semiconducting precipitate. This enhancement is attributed to a number of pinned vortices at the boundary.

*Key words:* scanning tunneling microscopy; scanning tunneling spectroscopy; vortex; pinning; $YNi_2B_2C$

## 1. Introduction

Flux pinning in type II superconductors has been studied extensively because of its physical interest and its importance for the applications of superconductors. In order to verify the effectiveness of various structural defects as a pinning center, the observation of the flux pinning has been performed with several techniques such as bitter decoration and Lorentz microscopy. However, these techniques are restricted to the observations in low magnetic fields because they sense the field distribution around vortices which changes in the scale of penetration length. On the other hand, scanning tunneling microscopy (STM) and spectroscopy (STS) have the potential to resolve the individual vortices at high magnetic fields[1] because STM/STS senses the superconducting order parameter directly. The trapped vortices at columnar defects in 2H-$NbSe_2$[2,3] and a twin boundary in $YBa_2Cu_3O_7$[4] have been observed by STM. In this paper, we present the observation of the vortex pinning around the semiconducting precipitate in $YNi_2B_2C$ by STS.

[1] Corresponding author. E-mail: sakata@rs.kagu.tus.ac.jp

## 2. Experimental

A single crystal of $YNi_2B_2C$ was grown by the floating zone method. The $T_c$ was determined to be 14.0K from the DC magnetization measurements. The STS measurements were performed using a laboratory-build LT-STM, which is able to be operated in vacuum down to 2.2K in magnetic fields up to 14.5T. In order to obtain a clean surface, the sample was pushed against the edge of a thin blade and cut or cracked in the LT-STM at 4.2K prior to measurements[5,6]. The external magnetic field was applied along the *a*-axis, that is, parallel to the tip-sample direction.

## 3. Results and Discussions

Figure 1 shows a map of the quasiparticle density of states at the Fermi energy, $N_s(E_F,r)$, at 4.2K in the magnetic field of 1T applied above $T_c$. We obtained the map by measuring the $I$-$V$ characteristics at 64x64 point on the sample surface and differentiating them. The vortex cores are imaged as the increase in $N_s(E_F,r)$, thus seen as white regions. The observed

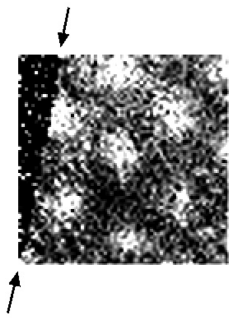

Fig. 1. A $N_s(\mathrm{E}_F,\mathrm{r})$ map of $\mathrm{YNi_2B_2C}$ at 4.2K in the magnetic field of 1T applied above $T_c$. The vortex cores are imaged as increase in $N_s(\mathrm{E}_F,\mathrm{r})$, thus seen as white regions. The arrows indicate the boundary between the superconducting and the semicondicting area. 150nm×150nm

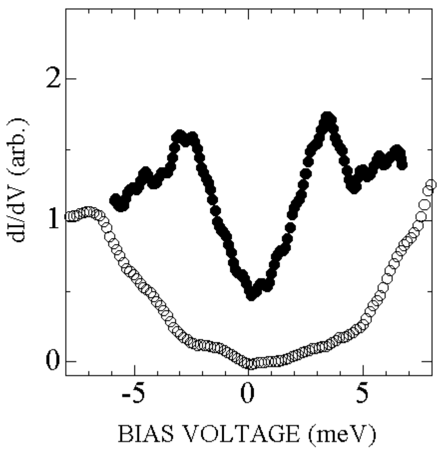


Fig. 2. $dI/dV$ spectra at the semiconducting area (open circles) and at the superconducting area (closed circles) at 4.2K in the magnetic field of 1T applied above $T_c$.

vortex cores formed distorted triangular lattice though the stable lattice at this field is a square one[5,6]. On the left part of Fig.1, an uniformly black area which indicates low density of states at the Fermi energy has been observed. A tunneling spectrum at this area is presented in Fig.2 and shows a semiconducting characteristic. This area is thought to be a precipitate which has slightly different composition from $\mathrm{YNi_2B_2C}$.

After the magnetic field is increased from 1T to 1.5T at 4.2K, the map of $N_s(\mathrm{E}_F,\mathrm{r})$ was observed at the almost same area where Fig.1 was obtained. As seen in Fig.3, in addition to the shrunken vortex lattice, the increase in $N_s(\mathrm{E}_F,\mathrm{r})$ has been observed along the boundary between the superconducting and the semiconducting area. This feature has not been seen in the magnetic field applied above $T_c$ and appeared when the magnetic field was changed at 4.2K. During the field change at 4.2K, the motion of the vortices across the boundary occurs in order to achieve the equilibrium configuration and results in the pinned vortices at the boundary. Thus, the increase in $N_s(\mathrm{E}_F,\mathrm{r})$ along the boundary is attributed to the pinned vortices at the boundary. As far as we know, this is the first observation of the pinning of vortices along the boundary of the precipitate at a high magnetic field.

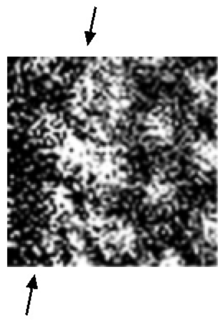

Fig. 3. A $N_s(\mathrm{E}_F,\mathrm{r})$ map at the almost same area as fig.1 after the magnetic field is increased from 1T to 1.5T at 4.2K. The arrows indicate the boundary between the superconducting and the semicondicting area. 150nm×150nm

In this experiment, the estimation of the pinning strength is an open question because the vortex configuration in the semiconducting area can not be obtained. However, the local flux density in the superconducting area is smaller than that expected from the external magnetic field. Thus, we presume that this type of pinning is significant in $\mathrm{YNi_2B_2C}$.

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