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# Critical properties of $MgB_2$ thin films on NbN/Si substrate under perpendicular magnetic fields

Akihiko Nishida [a,b,*], Chihiro Taka [a], Stefan Chromik [c], Rudolf Durny [b,d]

[a] Department of Applied Physics, Faculty of Science, Fukuoka University, 8-19-1, Nanakuma, Jonan-ku, Fukuoka 814-0180, Japan
[b] Advanced Materials Institute, Fukuoka University, 8-19-1, Nanakuma, Jonan-ku, Fukuoka 814-0180, Japan
[c] Institute of Electrical Engineering, Slovak Academy of Sciences, Dubravska cesta 9, 841 04 Bratislava, Slovak Republic
[d] Department of Physics, Faculty of Electrical Engineering, Slovak Technical University, Ilkovicova 3, 812 19 Bratislava, Slovak Republic

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## Abstract

Critical magnetic properties of $MgB_2$ thin films grown on NbN/Si substrate were investigated under magnetic fields perpendicular to the film surface. Polycrystalline $MgB_2$ films were prepared by sequential evaporation of boron and magnesium on NbN buffered Si substrate followed by an in situ annealing. AC and DC magnetizations were measured by the PPMS system. From the onset of AC diamagnetic susceptibilities, the upper critical fields were estimated resulting in the temperature derivative of about −5 kOe/K at lower temperatures. Critical current densities were evaluated from DC magnetization hystereses to be more than 1 MA/$cm^2$ below 14 K (self field). Critical properties including irreversibility fields were examined in comparison with those under parallel magnetic fields.


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*Keywords:* $MgB_2$ thin film; Upper critical field; Critical current; Irreversibility

## 1. Introduction

Since the discovery of $MgB_2$ [1], many intensive studies have been performed in bulk sintered samples [2–4], single crystals [5–7], and thin films [8–10]. Among these forms of samples, thin films are especially interesting from both basic and practical points of view. In our previous report [11], $MgB_2$ thin films were prepared by sequential evaporation, and the lower critical field $H_{c1}$ was studied with the magnetic field parallel to the film surface for avoiding the demagnetization effect. We

* Corresponding author. Tel.: +81 92 871 6631; fax: +81 92 865 6030.
*E-mail address:* nishida@cis.fukuoka-u.ac.jp (A. Nishida).

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observed linear temperature dependence of $H_{c1}$ and discussed it in relation to the basic nature of the gap state.

On the other hand, from the practical point of view, it is important to investigate the upper critical field $H_{c2}$ and the critical current density $J_c$. In order to examine the rigid current flow throughout the film, it is necessary to measure magnetization with the magnetic field perpendicular to the film surface. Another practical importance should be put on flux pinning and magnetic irreversibility, which actually determines the extent of applicability of superconductors. For example, $J_c$ will be very small under strong magnetic field without effective flux pinning centers, whose density is seriously affected by the sample quality and morphology. In this work, we investigate $H_{c2}$, $J_c$, and irreversibility under the perpendicular magnetic field, comparing them with the parallel field case.

## 2. Experimental

The $MgB_2$ thin film studied in this work is the same polycrystalline film as in the previous report [11]. The boron and magnesium layers were sequentially deposited on NbN buffered Si(1 0 0) substrate in vacuum. The thickness of the boron layer in the precursor film was adjusted so as to result in 200 nm stoichiometric $MgB_2$ film after reaction with the excess Mg top layer. The precursor film was in situ annealed in an Ar atmosphere. The obtained film was cut into five pieces and stacked together (putting PTFE film in between them) in order to fit inside the sample holding tube with its axis along the magnetic field.

Magnetic measurements were performed with magnetic field perpendicular to the film surface using PPMS magnetometer (Quantum Design). Temperature dependent AC susceptibility was measured with 1 G and 100 Hz excitation field, cooling at respective static fields. From the onset of the AC diamagnetic susceptibility for respective fields $H$, the transition temperature $T_{c2}(H)$ was evaluated thus providing the upper critical field $H_{c2}(T)$. In order to estimate the critical current density $J_c$, DC magnetization hystereses were measured at variety of constant temperatures. Values of $J_c$ were estimated on the basis of the Bean model, $J_c = 30\Delta M/r$, where $\Delta M$ is the height of the magnetization loop and $r = 0.13$ cm is the sample half-width. Irreversibility field $H_{irr}$ was also estimated from diminishing magnetization hysteresis.

## 3. Results and discussion

Onsets of the AC diamagnetic susceptibility $\chi'$ under various magnetic fields perpendicular to the film surface are partly shown in Fig. 1. As indicated by arrows, we estimated the transition temperature $T_{c2}(H)$ at respective magnetic fields $H$, from which we deduced $H_{c2}(T)$.

In Fig. 2, we indicate thus obtained $H_{c2}$ curve under the perpendicular field by the solid circles together with $H_{c2}$ under the parallel field (open circles). First we note that $H_{c2}$ curves for parallel and perpendicular fields show almost identical variation, and this is consistent with the polycrystalline character of our film. The slight difference may indicate slight tendency of preferred $c$-axis orientation perpendicular to the film surface.

At lower temperatures we estimate the temperature derivative, $dH_{c2}/dT$, being about $-5$ kOe/K.

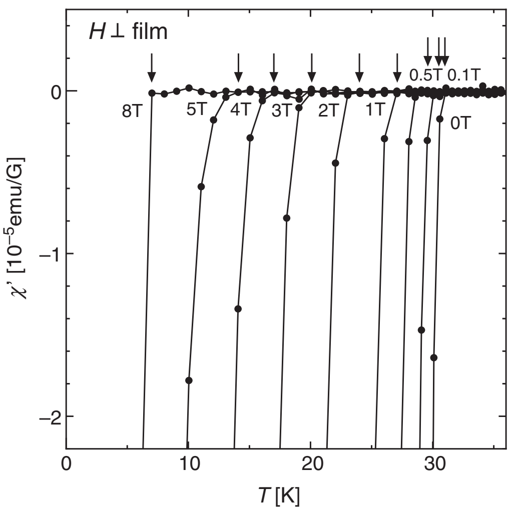


Fig. 1. Onsets of the AC diamagnetic susceptibility $\chi'$ upon cooling under various magnetic fields perpendicular to the film surface as indicated by arrows.