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# Parallel upper critical field of niobium/graphite bilayers

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**Abstract**

The influence of the superconducting proximity effect to the upper critical field ($H_C$) in niobium/graphite bilayers was studied and related to the ratio $T_C^*/T_C^S$: $T_C^*$ and $T_C^S$ are the transition temperature of Nb/KG film and that of Nb film respectively. The thickness of niobium (Nb) film was controlled about 40 nm, and that of graphite (kish graphite: KG) film ranged from 120 nm to 140 nm. For making a specimen, Nb was deposited on a KG film and a quartz glass substrate simultaneously, and magnetic field was applied parallel to the Nb/KG interface. $H_C$ of Nb/KG film ($H_C^*$) lowered from that of Nb film ($H_C^S$) at all temperatures within this work, and the value of $\Delta H_C$ defined as $H_C^S - H_C^*$ showed different temperature dependence among samples, depending on whether $T_C^*/T_C^S 1.00 <$ or $\geqq 1.00$. This behavior of $H_C$ suggests the additional existence of the interference of electrons in the clean KG film.
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## 1. Introduction

In bilayers of superconductor (S) and normal conductor (N), superconducting transition temperature ($T_C$) and critical field ($H_C$) lower from those in the superconductor itself [1–4]. On the other hand, it was recently reported by the authors that the ratio of $T_C$ of the niobium/graphite film ($T_C^*$) to that of the niobium film ($T_C^S$) showed a periodic characteristic with the graphite film thickness, furthermore, the peak values of the ratio exceeded 1.00 [5]. As the cause, it was suggested that the electron-electron interaction at the niobium/graphite interface changes depending on the graphite film thickness because of the interference of electrons in the graphite film. If the view is appropriate, upper critical field in niobium/graphite films should also be influenced by the graphite film thickness. Therefore, we studied experimentally the relation between the upper critical field of

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niobium/graphite corresponding to S/N bilayers and the thickness of graphite films.

## 2. Experimental

In this study, magnetic field **B** was applied parallel to the S/N interface, and the upper critical field was obtained by measuring the resistance of samples as shown in Fig. 1, which are essentially the same as that used in the previous work [5].

Since details of the sample preparation were already described [5], the outline is briefly given as follows. Firstly, a kish graphite (KG) was chosen as an original crystal with good crystal perfection. Thin graphite films as N were made by cleaving the KG, and they were kept on quartz glass substrates. The thicknesses of KG films used in this study were 122, 128, 135, and 142 nm, respectively. Niobium (Nb) films were made by electron-beam evaporation method, and the thickness was controlled about 40 nm corresponding to the coherence length of Nb.

After evaporation, each electrode was attached as shown in Fig. 1(b), so that each resistance of Nb and Nb/KG films could be measured at the same time, and it was taken care that the longitudinal direction of each film paralleled the applied magnetic field.

## 3. Results and discussion

A typical example of experimental results is shown in Fig. 2. The KG film thickness ($d_{KG}$) is 142 nm. The resistance ($R$) is normalized by $R_0$ which is the normal state value, and numbers in the figure indicate investigated temperatures normalized by the transition temperature of Nb film, namely $T/T_C^S$. The upper critical field ($H_C$) was defined as the field at which $R$ recovered sharply. In this sample, the transition temperature of Nb/KG film ($T_C^*$) was higher than $T_C^S$ about 0.1°. As for

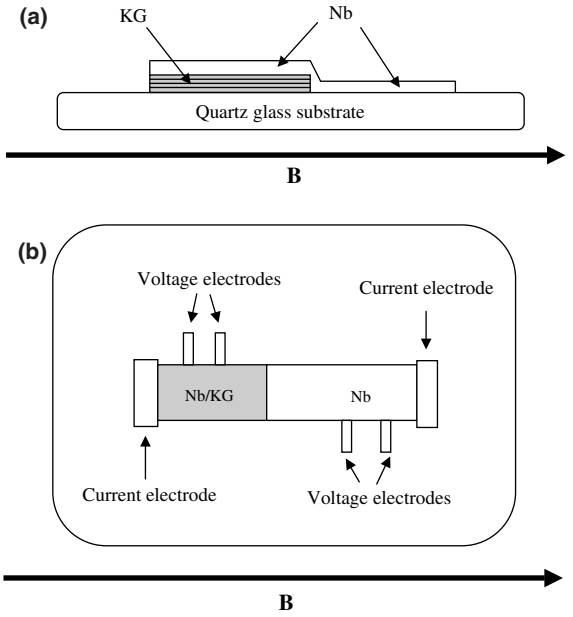


Fig. 1. Schematic diagram of a specimen (a) cross sectional view. Nb is deposited on the lamination of a KG film and a quartz glass substrate. (b) Electrode configuration. The longitudinal direction of Nb and Nb/KG films parallels to the magnetic field.

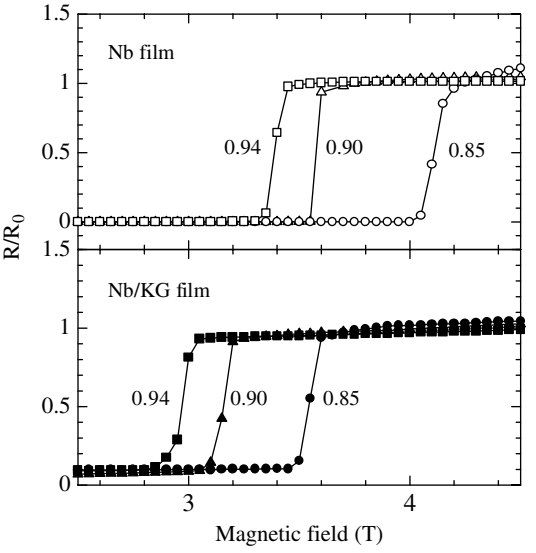


Fig. 2. Typical example of results. The open symbols (○,Δ,□) represent results of a Nb film, and the closed symbols (●,▲,■) represent those of a Nb/KG film. Nb film thickness is 40 nm and KG film thickness of Nb/KG film is 142 nm. Numbers indicate investigated temperatures normalized by the transition temperature of Nb film: $T/T_C^S$.

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