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OBSERVATION OF MAGNETIC DOMAINS IN IRRADIATED TRANSITION METALS BY HIGH VOLTAGE ELECTRON MICROSCOPY

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Abstract. – The effect of irradiation on the movement of domain walls was studied in ferromagnetic transition metals by using a high voltage electron microscope. In iron, a domain wall became easily movable at a 300 kV irradiation. The mobility was less affected in cobalt, while in nickel the effect was the greatest.

1. Introduction

It is well known that point defects in pure iron have an anomalous character compared with other transition metals. A band theoretical explanation was made by one of the present authors [1] for the anomalously high migration temperature of self interstitials in pure iron. According to this model, the domain wall movement in pure iron is expected to be less strongly affected by fast particle irradiation than in other transition metals, as the volume and the stress field of an interstitial iron atom is considered to be small.

The present study has been made in order to obtain experimental support of the model mentioned above by direct observation of domain walls in a high voltage electron microscope.

2. Experiment

Thin circular disc specimens were cut from single crystal ingots of iron, nickel and cobalt of purity 99.99%. Several polycrystalline specimens and a stress annealed specimen of iron of the same purity were also prepared. After electrochemical polishing, each specimen was brought into a high voltage electron microscope (HVEM), which has been operated in the Lorentz mode at room temperature. A magnetic field, of strength variable up to a maximum of 8 kA/m, could be applied along any direction in the plane of the specimen.

Magnetic domain walls were observed in the HVEM before and after electron beam irradiation. Before the observation a maximum external field was applied several times in order to stabilise the domain wall in one position. The electron beam irradiations were made at room temperature for 10 to 20 minutes at various irradiation voltages between 200 and 800 kV. During an irradiation, an electron beam current of about 10 nA was focused on a small area of about 10 μm² on the surface of the specimen.

The results of EM observations for a domain wall in the iron single crystal specimen after irradiation at 300 and 800 kV are shown in figures 1a and b respectively. The displacement of a domain wall in iron observed by increasing the external field from 1.6 to 6.4 kA/m is plotted against the irradiation voltage in figure 2a. In this figure it is shown that the domain wall displacement increases abruptly just below the atomic displacement threshold voltage of 312 kV [2]. It decreases with further increase of the irradiation voltage.

In the case of nickel, the effect was found to be much larger than in pure iron. A domain wall completely disappeared after 550 kV irradiation for 10 minutes. The observed displacement of a domain wall up to this voltage caused by increasing the external field from 0 to 1.6 kA/m is shown in figure 2b.

In cobalt, the effect of electron irradiation on the domain wall mobility is much smaller than in the other two metals. The observed displacement of a domain wall caused by increasing the external field from 0 to 6.4 kA/m is shown to figure 2c, where only a small increase of the domain wall mobility is seen at the irradiation voltage of 550 kV.

3. Discussion

An important factor determining the domain structure is the domain wall pinning by crystal defects and non-magnetic inclusions. Before beginning the present experiments, it had been expected that electron irradiation would result in domain wall pinning. Contrary to this expectation, the mobility of domain walls increased at an irradiation voltage around the atomic displacement threshold voltage. One of the reasons for this increase may be that the structure of some pinning centers especially near the surface of the specimen changed by the fast electron irradiation. With further irradiation at higher voltages, new pinning centers were created, which decreased the domain wall mobility. Thus, the initial increase and subsequent decrease of the domain wall mobility can be explained.
Fig. 1. — A pair of domain walls in an iron single crystal specimen observed in the HVEM after (a) 300 kV and (b) 800 kV irradiation for 10 minutes, in an increasing external field. Each micrograph corresponds to an area of 6.7 \( \mu \text{m} \times 8.7 \mu \text{m} \).

Fig. 2. — Displacements of domain walls in (a) iron, (b) nickel and (c) cobalt as functions of the irradiation voltage.

According to the band model, proposed in reference [1], the volume of self interstitial iron atom is expected to be smaller than in other two ferromagnetic metals. Therefore, it can be considered that domain walls in iron are less strongly affected by irradiation than the other two metals. The experimental results for cobalt suggest that the magnetocrystalline anisotropy also plays an important role. The first magnetocrystalline anisotropy constant in cobalt at room temperature is an order of magnitude larger than in iron, and in iron it is again one order of magnitude larger than in nickel. The observed change in the mobility of domain walls by the irradiation is also in the same order in the three metals. However, talking into account the domain structures in iron and in nickel, which are quite similar to each other and very different from those in cobalt, it may be concluded that the effect of irradiation on the domain walls in iron is smaller than in the other two ferromagnetic metals.

4. Conclusions

It was found that the mobility of domain walls increases by electron beam irradiation around the atomic displacement threshold voltage and decreases with further increase of the irradiation voltage. The effect of fast electron irradiation on a domain wall in iron was found to be relatively smaller than in other ferromagnetic metals. This fact is in good agreement with the band theoretical consideration.

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