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Laser-excited magnetic change in cobalt monocrystal

K. ROŻNIAKOWSKI
Institute of Physics, Technical University of Łódź, Wólczańska 219, 93-005 Łódź, Poland

Magnetic domains on the surface of a cobalt monocrystal are observed by scanning electron microscope (SEM). Changes in magnetic domain structure in local laser-treated areas were observed. At depths greater than 60 μm, both hexagonal and cubic phases exist. The phenomenon of refining of the Kittel open structure was recorded. The mechanism responsible for the transition between the two different domain structures is briefly discussed.

1. Introduction

Cobalt monocrystal can appear in the hexagonal and cubic phases with different crystallographic lattices. The transition from one form to the other (called martensite transformation) is observed at a strictly determined temperature, T_m. This monocrystal is a ferromagnetic material below the Curie temperature T_c, which is higher than the T_m temperature. In the ferromagnetic phase of a cobalt monocrystal, a magnetic domain structure is expected.

In the hexagonal phase a strong magnetic anisotropy along the [0 0 0 1] axis is observed. This yields a strong magnetic field outside the surface perpendicular to the anisotropy axis, and means that the conditions of open domain structure creation (Kittel domain structure) are satisfied. The surface of materials with such a domain structure produces type-I magnetic contrast in the SEM observations [1].

The magnetic domain structure created in the cubic phase is a closure structure of the Landau–Lifshitz type. The surface of the material with such a domain structure, seen by SEM, leads to type-II magnetic contrast [1].

The aim of the present work is to investigate the change in magnetic structure in the area treated by laser-pulse radiation.

2. Experimental procedure

Cobalt monocrystal, oriented by means of an X-ray diffractometer, was cut from a sample of suitable quality so that the observation plane was perpendicular to the direction of the magnetic anisotropy axis [0 0 0 1]. To eliminate disturbance sources of the image (topographic contrast) the specimen surface was ground off and polished mechanically with different powders. This surface was exposed to pulse radiation of laser KVANT 15 ($E = 8.0$ J, $t = 4.5$ ms, $\lambda = 1.06$ μm) so that the area of laser operation would melt a locally thin layer of material. The exposure was made in atmospheric air (300 K). The picture of domains visible in the observation plane (owing to the magnetic contrast of the first type) was registered by SEM (BS 300 type). The chemical constitution of irradiated areas was analysed by X-ray microprobe in cooperation with SEM (DSM 950B type).

To observe the martensite transformation in relation to the depth of laser heating, successive layers of the specimen 60 and 100 μm thick, parallel to the observation plane, were ground off. At the same time a suitable SEM registration was made.

3. Results

A maze pattern of magnetic contrast typical for cobalt monocrystal, observed by SEM on the surface prepared for laser exposure, is presented in Fig. 1. The width of observed domains (the distance between adjoining walls of domains in the direction perpendicular to them) is 75 μm. This value is close to that measured by Polanski and co-workers [2].

In rapidly-frozen areas (before melting by laser-pulse radiation) axial–symmetrical structures were noticed (Fig. 2). These have been observed previously [3–9], and have been called ring structures [4], transient capillary waves [4–8], or ring waves [3]. Their presence means that the superficial layer of the exposed area was molten and its temperature was not lower than 1766 K (the melting point of cobalt). The local chemical constitution of the molten area is presented in Fig. 3.

On the surface of the molten areas, and also in their close surroundings, open Kittel structures were not observed. While observing the structure of domains in relation to the depth of laser heating, it was noticed that if the layer of 60 μm is ground off, then there are small areas where Kittel domains occur (Fig. 4), but these have no maze pattern. However, their width is smaller as compared to the width of domains which are observed before laser treatment.

If the layer of 100 μm is ground off, then in the laser-heating region there are larger areas as compared to those mentioned above where Kittel open structures occur (Fig. 5). In addition, in some areas of the laser

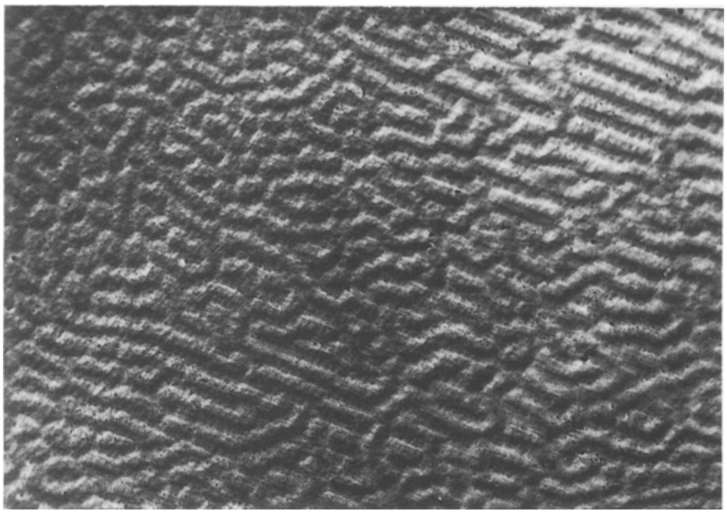


Figure 1 The magnetic domain structure on a cobalt monocrystal surface at room temperature (before laser interaction). Type 1 magnetic contrast. Average width of observed domains, 75 μm.

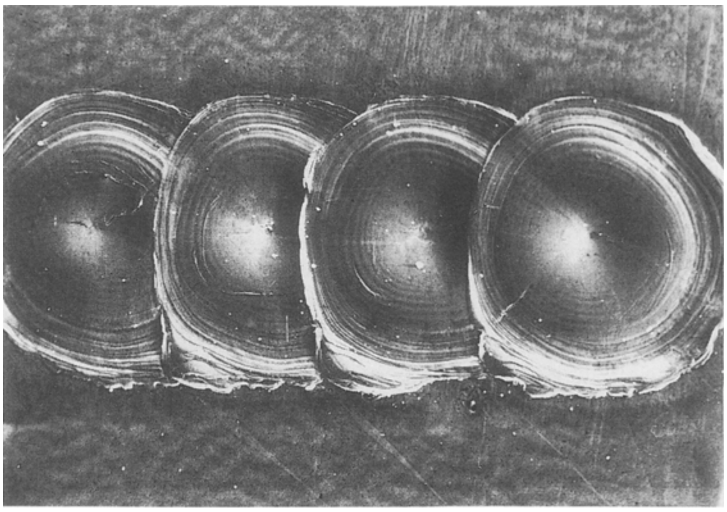


Figure 2 Laser-excited transient capillary waves in rapidly frozen areas. Average diameter of these areas, 700 μm.

heating boundary we can see a maze pattern typical for cobalt monocrystal. The width of these domains is about four times smaller than the domains observed before laser heating (Fig. 6).

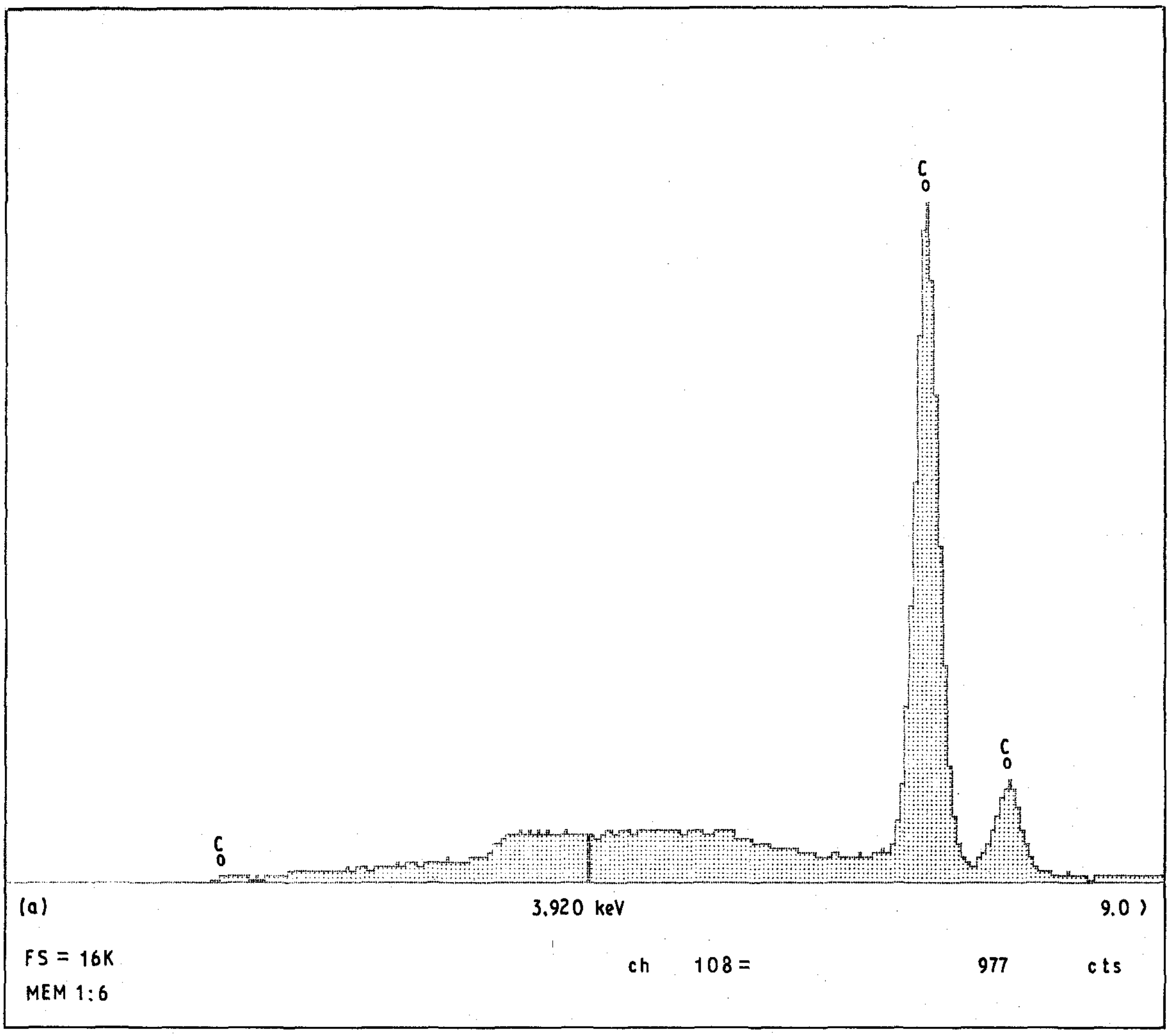
4. Discussion

When pulse laser radiation is incident on an absorbing material, dramatic effects associated with the laser-induced temperature change can occur. These effects may include not only melting and vapourization of the absorbing material, but also local heating of the target. In addition, if the laser pulse is switched off, the irradiated region is rapidly cooled. In the present investigations we assumed that the laser-treated material is locally melted, heated and cooled; a schematic cross-section of this region is presented in Fig. 7. The martensite transformation isotherm T_m divided the irradiated region in two parts.

If the layer of H_m (the distance from surface to boundary of martensite transformation) is ground off, then we may have had material which was not heated higher than T_m. The boundary between these regions is not sharp because four liquid craters were made (Fig. 2) and the geometry of heat transport and the plane of abrasion are different (not parallel). For these reasons we observed only some areas where Kittel open structures occur (Fig. 5).

A similar process was observed by Polański and co-workers [2]. In their experiment, a cobalt monocrystal specimen was heated and cooled by conventional methods. At the same time, magnetic contrast was observed. The mechanism of creation of a Kittel-type domain structure proposed by these authors may also be used in the present work.

At a depth of 100 μm, however, a distinct border between the area where the domains occur (i.e. not exposed to laser radiation), and the molten and frozen area, is not observed. Moreover in many parts of this area, there are visible maze domains (Fig. 6) with a width several times less than that of primary domains (before laser radiation). They occur both independently and 'on the background' of the wide domains. It



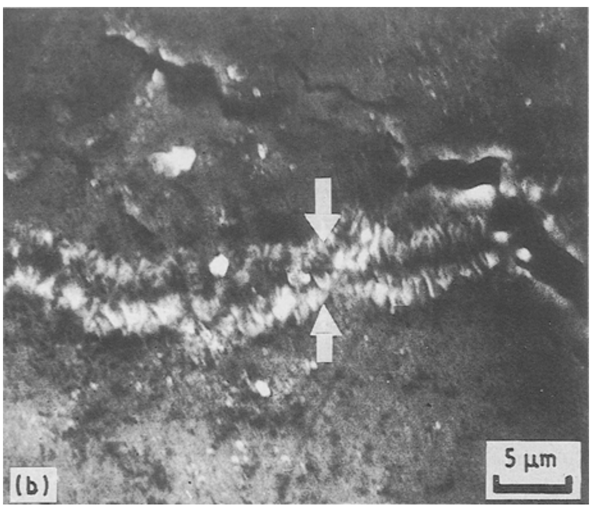


Figure 3 (*a*) Local chemical constitution measured in the central part of (*b*) frozen area.

Figure 4 Structure of domains (in irradiated area) if a layer of 60 µm is ground off. Open type of domain in this region is hardly visible.

must be presumed that a certain refinement of the domains is observed, similar to the phenomenon which takes place when mechanical stress is incorporated in the surface of coarse-grained electric sheet (iron–silicon alloy) [10].

5. Conclusions

On the surface of cobalt monocrystals in local-laser molten areas, open Kittel structures were not observed. The hexagonal phase does not occur on this

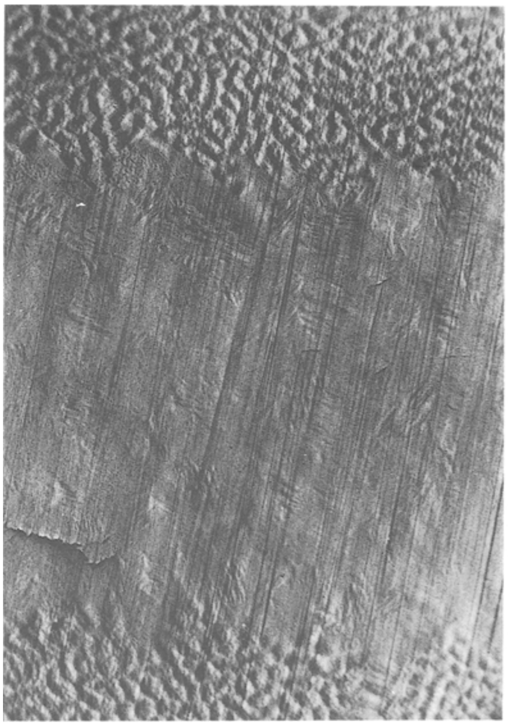


Figure 5 Structure of domains if a layer of 100 μm is ground off.

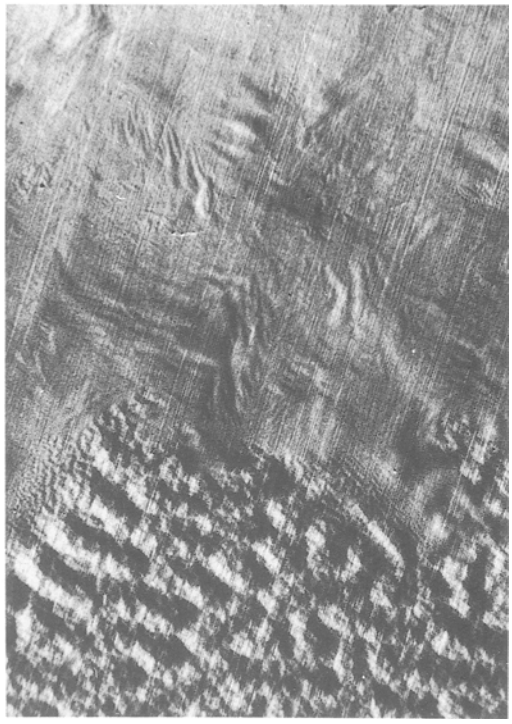


Figure 6 Refinement of the Kittel-type domains.

surface. The phenomenon of refinement of Kittel open structures was observed. It seems that at depths of 100 μm, both hexagonal and cubic phases exist.

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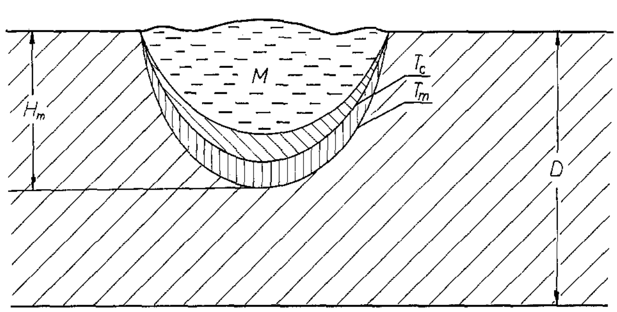

Figure 7 Schematic cross-section of irradiated area. M, melted material; T_c, Curie isotherm; T_m, martensite transformation isotherm; H_m, distance from surface to boundary of martensite transformation; D, sample thickness ($D \gg H_m$).

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