Kenji SUZUKI, Hidetoshi UENO, Tsugiko TAKASE, Katsuhiko YAMAGUCHI

Fukushima University

Development of a new micro-MOKE magnetometer combined with magnetic domain scope

Abstract. *A measurement system was developed for observation of magnetic domains and micro-MOKE on same field of vision. The system is available for measuring B-H curve at a spot with micro-scale after a confirmation of magnetic domain patterns. The measurement system has a possibility to detect the magnetization process of locally agglutinated magnetic materials buried in non-magnetic materials.*

Streszczenie. *W artykule przedstawiono nowy magnetometr typu mikro-MOKE. Omawiany system ma możliwość pomiaru charakterystyki B-H w skali mikro przy ustalonej domenie magnetycznej oraz wykrywania procesu magnetyzacji w miejscowo sklejonych materiałach magnetycznych, zagrzebanych w materiałach niemagnetycznych. (**Rozwój magnetometru typu mikro-MOKE – zagadnienie zasięgu domen magnetycznych**).*

Keywords: micro-MOKE, magnetic domain scope, grain boundary magnetism, Alloy600.
Słowa kluczowe: mikro-MOKE, pole domeny magnetycznej, magnetyzm na granicy ziaren, Alloy600.

Introduction

Recently micro magneto-optical Kerr effect (μ-MOKE) magnetometers have been used well for study of micro-magnetics, because they are useful measurement equipment to detect small area (μm range) magnetization process of magnetic materials. Usually μ-MOKE magnetometers are applied for magnetic thin film samples with a homogeneous composition on substrates. Although it becomes difficult to detect the magnetization process for locally agglutinated magnetic materials, e.g. dispersed minute magnetic particles in non-magnetic medium, the reason why is that it is hard to find the localized magnetic area distinguishing from non-magnetic area. On the other hand, magnetic domain scopes, whose principle is also MOKE, are suitable for finding the magnetic area in the region of around 100 μm square, though it is almost impossible to measure the local magnetization process precisely. Then we tried to develop a new μ-MOKE magnetometer combined with a magnetic domain scope.

The new μ-MOKE magnetometer can focus the laser spot on localized magnetic area observing the magnetic domain simultaneously in same sight. Therefore the equipment can realize to detect the magnetization process of locally agglutinated magnetic materials which are buried in non-magnetic materials. In this paper we introduce the new μ-MOKE magnetometer and present a result using the equipment for a local magnetization process on a grain boundary of Ni based alloy.

μ-MOKE magnetometer combined with magnetic domain scope

The new μ-MOKE magnetometer has two optical paths. One has a light source of a diode laser with the wave length of 408nm for μ-MOKE detecting and other has a Mercury lamp for magnetic domain scope. Both optical paths penetrate a common objective lens whose magnification has x20 or x50 above a sample. Figure 1 shows a schematic view for magnetic domain configuration. In this use, the polarized light through a polarizer from Mercury lamp penetrates the edge of objective lens to incident a sample surface obliquely for domain observation using in-plane Kerr effect. Figure 2 shows a diagram for in-plane μ-MOKE arrangement with same field of vision of magnetic domain scope. Then the light path from Mercury lamp source penetrates the center of the objective lens. Moreover this measurement system can switch the light path for polar magnetic domain observation and polar μ-MOKE measurement.

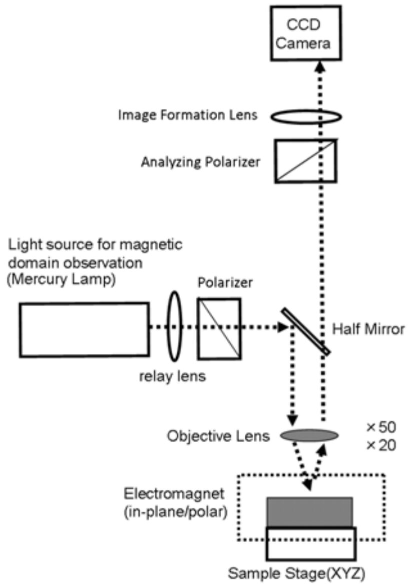

Fig.1. Outline drawings of magnetic domain scope.

Observation range of domain scope is 250x200 μm for x20 lens and 100x80 μm for x50 lens. The spatial resolution of μ-MOKE is ϕ 2~3 μm. Max applied magnetic field is ±3 kOe for polar Kerr and ±5kOe for in-plane Kerr. The sight view of magnetic domain scope is captured by a 80 Megapixel monochrome CCD camera. The laser light modulated by photoelastic modulation (PEM) is detected by high speed pin photodiode and the signal is analyzed by lock-in amplifier with reference frequency of PEM.

The equipment has the advantage of simultaneous measurement both for μ-MOKE and magnetic domains. The superior feature makes possible to detect the magnetization process after just focussing the localized magnetic area confirmed by domain view stood out sharply under the applied magnetic field.

System check using magnetic alloys

To check the measurement system, magnetic domains and μ-MOKE were measured for a rotary magnetic scale made by UV-LIGA method as shown in Fig.3 [1]. The size of one magnetic rectangular parallelepiped is 50x50x2000μm made of Fe-Ni alloy (Permalloy). Many tiny magnetic domains due to the surface roughness were observed by the domain scope as shown in Fig.4.

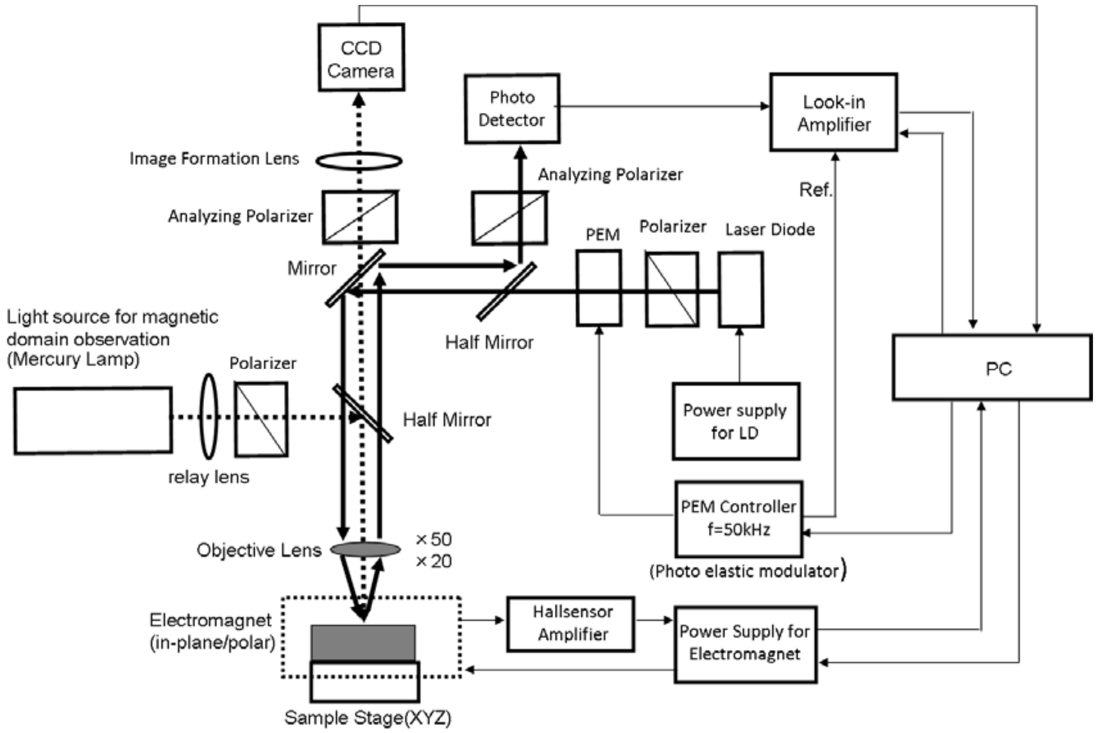

Fig.2. Outline drawings of μ-MOKE magnetometer combined with magnetic domain scope.

Figure 5(a) shows B-H curves at the center of a rectangular parallelepiped under applied magnetic field with the direction parallel and perpendicular for longitudinal direction using μ-MOKE. Figure 5(b) shows B-H curves at the center and the edge of a same rectangular parallelepiped. It is clearly seen that B-H curves have the shape anisotropy. Through the measurement checking including the test for other magnetic samples, it was shown that the system has sufficient ability as magnetic domain scope and μ-MOKE magnetometer.

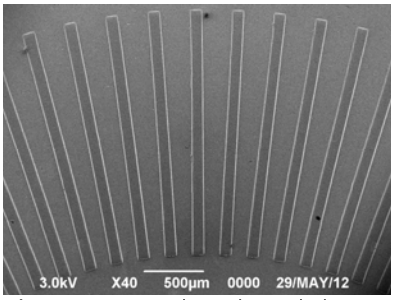

Fig.3. Image of a rotary magnetic scale made by UV-LIGA method observed by Scanning Electron Microscope (SEM).

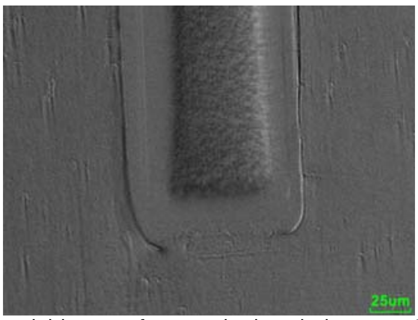

Fig.4. Differential image of magnetic domain between 850 Oe and -200 Oe applied in a rotary magnetic scale.

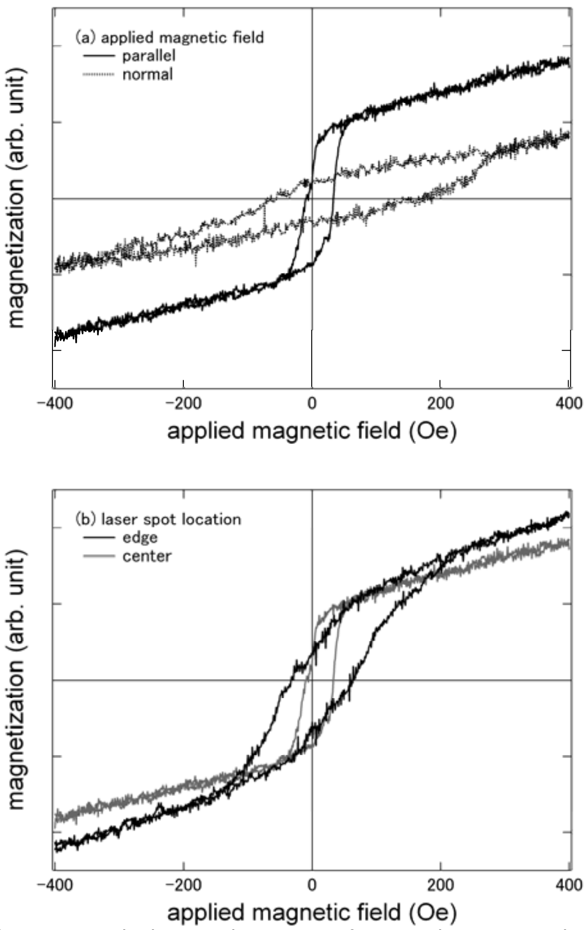

Fig.5. Magnetic hysteresis curves of magnetic structure in the magnetic rotary scale. These were measured by μ-MOKE magnetometer. Figure (a) shows direction dependence for applied magnetic field and (b) shows location dependence of magnetic scale.

Application for localized magnetic area on grain boundary of Alloy 600

To demonstrate the effectiveness of the new μ- MOKE magnetometer, we will show the experimental results for Ni based alloy; Alloy 600 (Inconel). Although Alloy 600 is originally a non-magnetic material in room temperature, it is known that it has tiny magnetization after the sample was sensitized by thermal treatment as shown in Fig.6 which is the results of B-H curves for Alloy 600 sensitized under 650°C for 0 and 5 hours measured by superconducting quantum interference device (SQUID) magnetometer at room temperature. The change due to the degradation is caused by Cr depletion on grain boundaries and the magnetization produces just only around grain boundaries [2]-[5]. Usually detecting of the magnetization process of such a grain boundary by μ-MOKE is difficult, because polishing treatment of sample surface for the optical measurement prevents from distinguishing grain boundaries from grains using ordinary optical microscope. Figure 7 shows scanning electron micrograph (SEM) for the surface of sensitized Alloy 600. In Fig.7(a), grain boundaries are clearly seen as grooves. If μ-MOKE measurement is attempted for the surface, the grooves scatter the laser beam. On the other hand, after sufficient polishing of the surface, almost grain boundaries can not be distinguish from grains as shown in Fig.7(b).

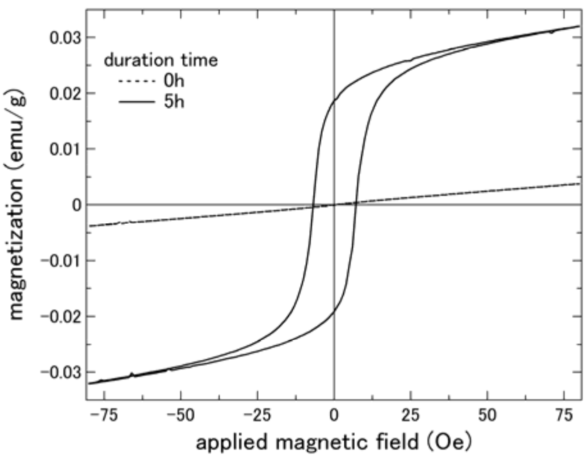

Fig.6. B-H curves for Alloy 600 sensitized under 650°C for 0 and 5 hours measured by superconducting quantum interference device (SQUID).

Figure 8(a) shows the observed domain view of thermal treated Alloy 600 under zero magnetic fields and the grain boundaries are not seen almost clearly. Figure 8(b) which is a differential image between the applied magnetic field of ±500Oe, however, shows apparent boundaries as shown in the area marked by a ellipse. This means the boundary appears for its magnetism. Then the laser spot for μ-MOKE can be focused easily on a grain boundary, and the magnetization process can be measured as shown in Fig.9(a). In the same way, if the laser spot put inside the grain away from grain boundaries, the result of the magnetization process does not show any hysteresis as shown in Fig.9(b).

The shape of B-H curve on the grain boundary measured by μ-MOKE magnetometer in Fig.9(a) is different from the one of bulk by SQUID in Fig.6. This may be due to a shape anisotropy of grain boundary magnetism, that is, a B-H curve of Alloy 600 bulk is a result from average of B-H curves of boundaries which have different directions. It will be possible that each magnetic property of a boundary is investigated using the new μ-MOKE magnetometer combined with the magnetic domain scope.

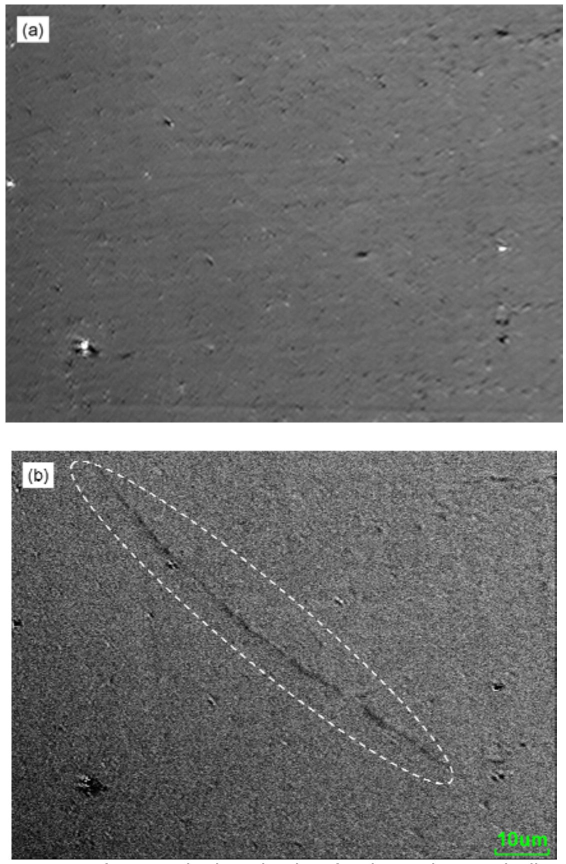

Fig.8. Image of magnetic domain view for thermal treated Alloy 600. (a) is under zero magnetic fields and (b) is a differential image between the applied magnetic field of ±500Oe.

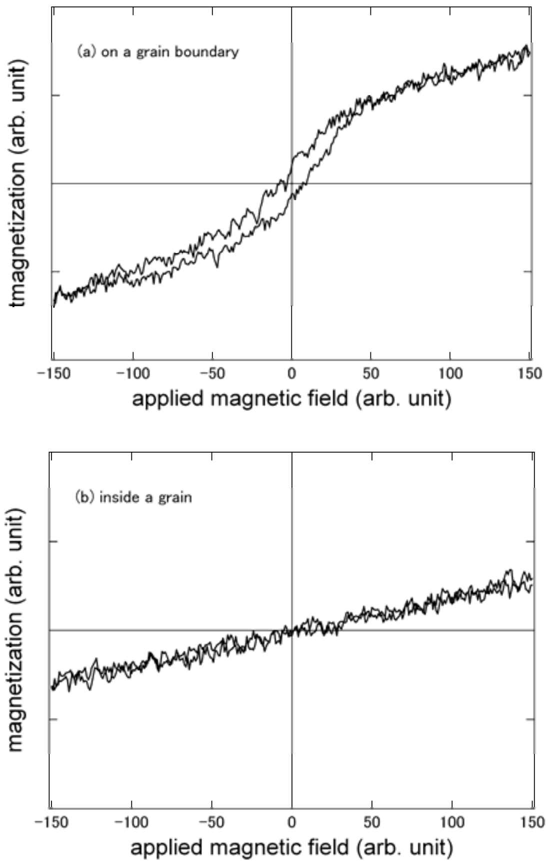

Fig.9. Magnetic hysteresis curves measured by μ-MOKE magnetometer (a):on a grain boundary and (b):inside a grain.

Conclusion

The new μ-MOKE magnetometer is very useful to detect the localized magnetization process and the measurement technique using the equipment will be available for various samples with locally agglutinated magnetic materials.

Acknowledgment

We would like to thank Dr. Koichi Akahane in Neoark, Ltd for his help to develop the new μ-MOKE magnetometer.

REFERENCES

[1] Y. Sampei, H. Anzai, Y. Itoh, O. Maeda, H. Nakamura, S. Osanai, K. Yamaguchi, O. Nittono, Journal of the Magnetics Society of Japan Vol. 33 (2009), No. 2, 118-121.

[2] R. G. Aspden, G. Economy, F. W. Pement and I. L. Wilson, *Metallurgical Transactions*, vol. 3 (1972), pp. 2691-2697.

[3] S. Takahashi, Y. Sato, Y. Kamada and T. Abe, *Journal of Magnetism and Magnetic Materials*, vol. 269 (2004), pp. 139-149.

[4] S. Takahashi, H. Sato, Y. Kamada, K. Ara and H. Kikuchi, IOS Press, vol. 19 (2004), pp. 3-8.

[5] K. Yamaguchi, K. Suzuki, T. Takase, O. Nittono, T. Uchimoto, T. Takagi, Physica B:Condensed Matter, vol.407 (2011), 1420-1423.

Authors: *Prof. Dr. Katsuhiko Yamaguchi, Faculty of Symbiotic Systems Science, Fukushima University, 1 Kanayagawa, Fukushima, 960-1296, Japan, E-mail: yama@sss.fukushima-u.ac.jp; Kenji Suzuki, E-mail: s1071007@ipc.fukushima-u.ac.jp; Hidetoshi Ueno, E-mail: s0810025@ipc.fukushima-u.ac.jp; Dr. Tugiko Takase, E-mail: ttakase@sss.fukushima-u.ac.jp.*