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# Spin-polarized Scanning Electron Microscopy for Analysis of Magnetic Devices

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Spin-polarized scanning electron microscopy (spin SEM)[1] is a method, which measures spin polarizations of secondary electrons, for observing magnetic domains. The main characteristics of spin SEM images are high spatial resolution, topography independency, and the capability of magnetization vector analysis in three dimensions. Taking advantages of these characteristics, spin SEM is expected to play an important role in evaluating magnetic devices such as recording media and permanent magnets. In our laboratory, Matsuyama et al. developed a spin SEM with a resolution of 20 nm in 1994.[2] However, as the density of the magnetic recording system increases rapidly, bit length has become as short as 20 nm.[3] The resolution of our previous spin SEM has therefore not been high enough for evaluating current magnetic devices. Accordingly, in this study, we developed a new approach to produce spin SEM images with higher resolution by improving the conventional spin SEM.

To achieve high-resolution observation, working distance (WD), which is defined by the length between the objective-lens exit and the sample surface, should be reduced. In spin SEM, however, the secondary-electron collector must be placed very close to the sample for collecting as many secondary electrons as possible (to compensate the insufficient efficiency of the spin detector). This requirement causes interference between the objective lens and the secondary-electron collector. Up till now, therefore, WD could not be reduced very much. In our previous system[2], as shown in Figs. 1(a), WD was 20 mm.

In the present study, we developed a new secondary-electron collector, as shown in Figs. 1(b), which achieves WD of 10 mm. This collector is composed of three spherical deflectors and several cylindrical lenses. The first deflector is set between the gun and the sample, and the probe beam is projected onto the sample through the holes in the outer spherical lens of the first deflector. It is very compact; therefore, WD can be reduced down to 10 mm. On the other hand, it can collect almost all secondary electrons because it is set just above the sample surface. The secondary electrons from the sample surface are deflected by 45 degrees and sent to the second deflector. When the second deflector is not activated, the electrons go straight through the hole in the outer lens of this deflector and enter the secondary-electron detector set behind it. SEM images can therefore be observed in this "not-activated" mode (namely, SEM image mode). When this deflector is activated, the secondary electrons are deflected by 60 degrees and sent to the third deflector, where they are deflected again by 15 degrees and transferred to the spin detector. This configuration has the advantage that either a magnetic-domain image or a topography image can be chosen by switching the second deflector on and off. In SEM image mode, the sample position can be set, and the probe-beam shape can be adjusted precisely. In our conventional configuration,[2] the probe beam had to be adjusted using an absorption-current image, in which the S/N ratio is not very good and probe-beam shape is difficult to adjust precisely. Our new configuration makes it possible to produce magnetic domain images, after adjusting the probe beam according to an SEM image, by switching the second deflector on and transferring the secondary electrons to the spin detector. Moreover, as in a conventional spin-SEM system, in the new configuration, the conventional optics from the third deflector to the spin detector can be used.

By observing a standard specimen for SEM, we confirmed that the probe beam in the new configuration can be as fine as 10 nm. To demonstrate the characteristics of spin SEM, we observed two magnetic structures. The first is a recorded-bit structure on a perpendicular magnetic-recording system (Fig. 2). Here, very short bits with length of 23 nm were observed to be correctly written. The other is a magnetic-domain structure in sintered NdFeB, studied as a permanent magnetic material (Fig. 3). All three magnetization components are shown here, and it is clear that the magnetization is mainly aligned in the *y*-direction. These results show that the spin SEM with this new optics configuration is a powerful tool for studying various magnetic devices.

[1] K. Koike and K. Hayakawa: *Jpn. J. Appl. Phys*., **23**, L187 (1984)
[2] H. Matsuyama and K. Koike; *J. Electron Microsc*. **43**,157 (1994)
[3] Y. Hsu, et al., *IEEE Trans. Magn. MAG* ***43***, 605 (2007).

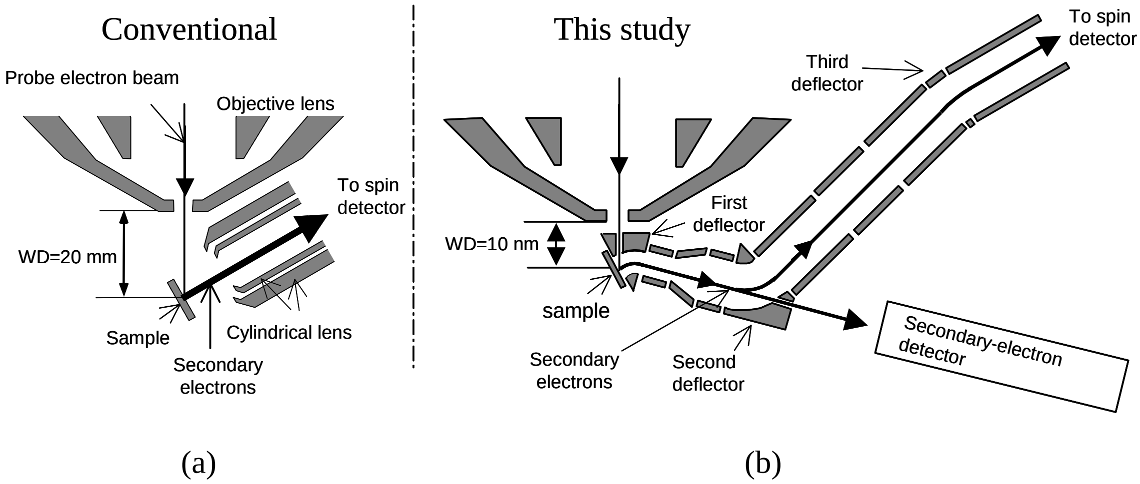


FIG. 1. Configuration of objective lens, sample, and secondary-electron collector in (a) conventional and (b) newly-designed spin SEM

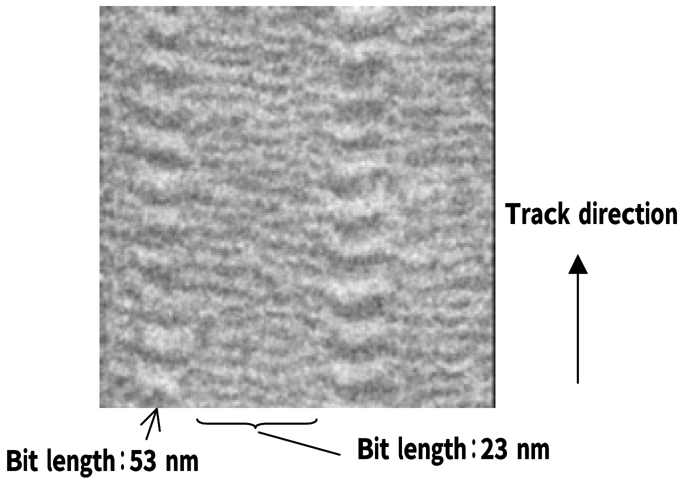


FIG. 2. Spin SEM image of the recorded bit structure in a perpendicular recording system. Tracks run in the vertical direction, and each black-and-white contrast shows one bit

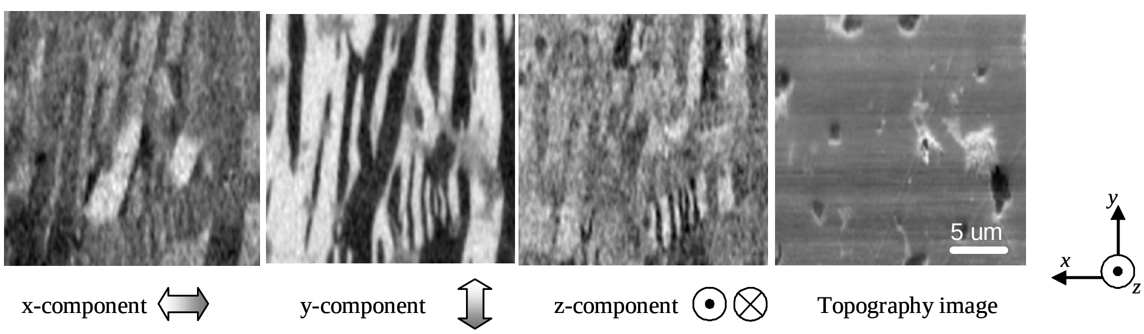


FIG. 3. Spin-SEM image of sintered NdFeB