Spin-polarized TEM using an NEA photocathode

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Great advances have been made in magnetic recording technology and spintronic devices, which are promising for high-density storage devices [1–3]. Such devices are expected to lead to the development of systems that can analyze magnetic and spin states with a nanometer-order spatial resolution. Already an electron beam holography and a Lorentz electron microscopy have been used for observation of magnetization state of magnetic recording media as well as spin-detection scanning electron microscopy where image resolution is, however, restricted to larger than 5 nm [4]. A spin-resolved STM (SP-STM) realizes the performance in atomic scale [5]. Although the SP-STM can only observe the surface state of spin, and the measurable direction of magnetization is limited due to the probe tip. It is important that the inner spin-state can be observed directly in arbitrary direction with atomic scale.

We have been seeking to combine electron microscopy and accelerator technology to realize a spin-polarized transmission electron microscope (SPTEM), which consists of a polarized electron source (PES) and a conventional TEM. We have commenced developing a PES for a TEM [6]. Spin-polarized electrons can be generated using an optical orientation of appropriate III–V semiconductors and vacuum extraction that uses a negative electron affinity (NEA) surface. Several beam parameters (including the electron spin polarization (ESP), the quantum efficiency (QE), and the beam emittance) of the PES are vastly superior to those of conventional thermal electron beams. In addition, it has the ability to generate a sub-nanosecond multibunch beam. A high ESP of 92% and a high QE of 0.5% have been realized using a GaAs–GaAsP strained superlattice photocathode with a 100-nm-thick active layer that was excited with 780 nm wavelength light [7,8]. This high-performance PES will enable dynamic observation of magnetic structures with high spatial and temporal resolutions as pulsed TEM or DTEM.

FIG. 1 (a) and (b) show photographs and a schematic diagram of the SPTEM system, respectively. The SPTEM consists of a PES, a TEM lens system that includes a spin manipulator, an objective-lens system, a projector-lens system, and an image-detection system. The PES has been designed and constructed with optimization for SPTEM [6]. The beam energy is set to be below 40 keV, that is a lower energy type as a TEM, because the spin interaction with condensed matters is very small comparing with the Coulomb interaction [9]. We have succeeded in development of the SPTEM. We have also demonstrated that the SPTEM can provide both TEM images and the diffraction patterns. FIG. 2 (a) shows a TEM image of a [001] oriented iron thin film using the polarized electron beam with the beam energy of 30 keV. FIG. 2 (b) shows a diffraction pattern of the iron specimen which is same as FIG. 2 (a).

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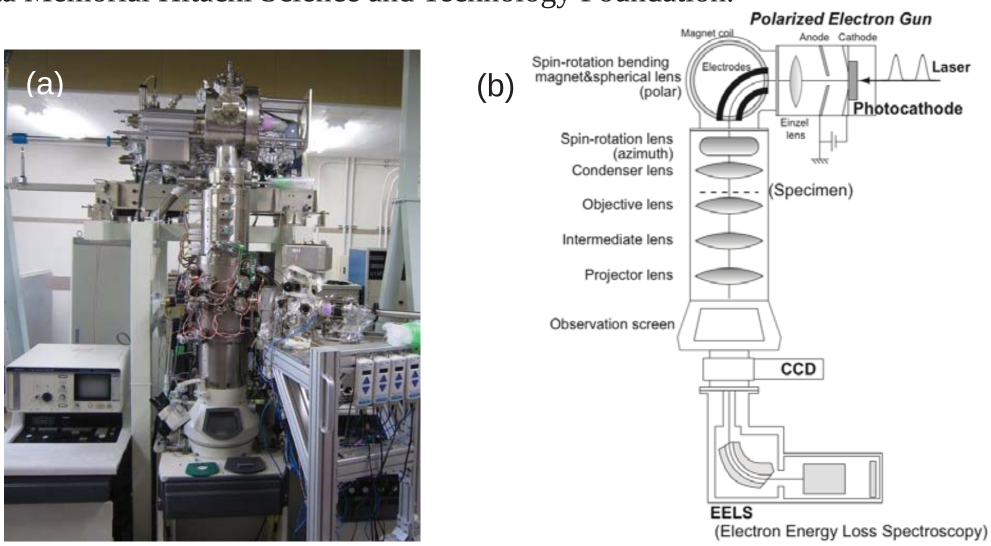

FIG. 1. (a) Photograph of a SPTEM and (b) schematic of the SPTEM and components.

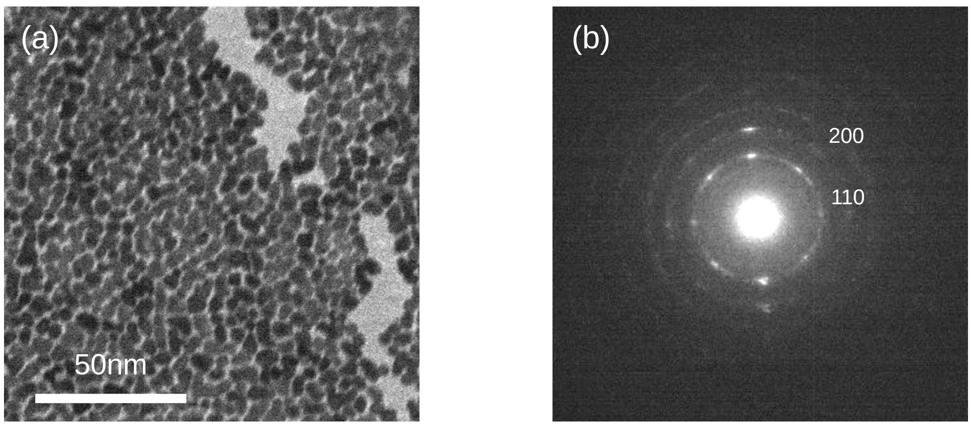

FIG. 2. (a) TEM image of an iron thin film by vacuum deposition with the SPTEM. (b) Corresponding diffraction pattern of the specimen.