Spatial and Temporal Coherences in Spin-Polarized Transmission Electron Microscopy

M. Kuwahara[1], S. Kusunoki[1], Y. Nambo[1], K. Sameshima[1], K. Saitoh[1,2], T. Ujihara[1], H. Asano[1], Y. Takeda[3,4], N. Tanaka[1,2]

[1]Graduate School of Engineering,, Nagoya University Nagoya, 464-8603, Japan
[2]EcoTopia Science Institute, Nagoya University, Nagoya 464-8603, Japan
[3]Nagoya Industrial Science Research Institute, Nagoya 464-0819, Japan
[4]Aichi Synchrotron Radiation Center, Aichi Science and Technology Foundation, Seto 489-0965, Japan

Great advances have recently been made in magnetic recording technology and spintronic devices, which are promising for high-density storage devices. 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 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. It is important that the inner spin-state can be observed directly in arbitrary direction with an atomic scale.

We have commenced a development of a spin-polarized transmission electron microscope (SPTEM), which consists of a polarized electron source (PES) and a conventional TEM [1-3]. Spin-polarized electrons can be generated using an optical orientation of III–V semiconductors and vacuum extraction that uses a negative electron affinity (NEA) surface. Several beam parameters of the PES are vastly superior to those of conventional thermal electron beams. In addition, it has the ability to generate a sub-picosecond multibunch beam[4]. 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 [5]. This high-performance PES will enable dynamic observation of magnetic structures with high spatial and temporal resolutions as pulsed TEM or DTEM.

We have already demonstrated that the SPTEM can provide both TEM images and the diffraction patterns [1]. The TEM images can be obtained in a spatial resolution of 1 nm in a 30-kV acceleration voltage. The apparatus has a 240-meV energy width of electron beam in the TEM without any monochrometors. The energy width indicates the temporal coherence is about 2.7 fs (longitudinal coherence of 2.7×10^{-7} m) at 30-keV beam energy. A brightness is measured by taking a spot size and a convergent angle on an image plane. The measured brightness is about 6.4×10^{7} A/cm^2.sr in a condition of 30-keV beam energy, an excitation wavelength of 780-nm and a drive-laser power of 20 mW (670 kW/cm^2) on the photocathode. The brightness for a 200-kV beam energy is 4×10^{8} A/cm^2.sr which is converted by using a Lorentz factor. The order of the brightness is enough to do an interference experiment. We also demonstrated interference fringes of spin-polarized electron beam by using a newly installed biprism. These results indicate the SP-TEM can provide enough coherence in both lateral direction and longitudinal direction even if the semiconductor photocathode is used for an electron emitter.

The authors thank Drs. H. Shinada, M. Koguchi and M. Tomita of Hitachi Central Research Laboratory for fruitful discussions and encouragement. This research was supported by MEXT KAKENHI Grant Number 51996964, 24651123, 25706031 and Kurata Research Grants from the Kurata Foundation.

References
[1] M. Kuwahara et al., Appl. Phys. Lett. **101** (2012) 03310
[2] M. Kuwahara et al., AMTC Letters **3** (2012) 180.
[3] M. Kuwahara et al., J. Phys.:Conf. Ser. **298** (2011) 012016.
[4] Y. Honda, et al., Jpn. J. Appl. Phys. 52, 086401-086407(2013).
[5] X.G. Jin et al., Appl. Phys. Express **1** (2008) 045002.

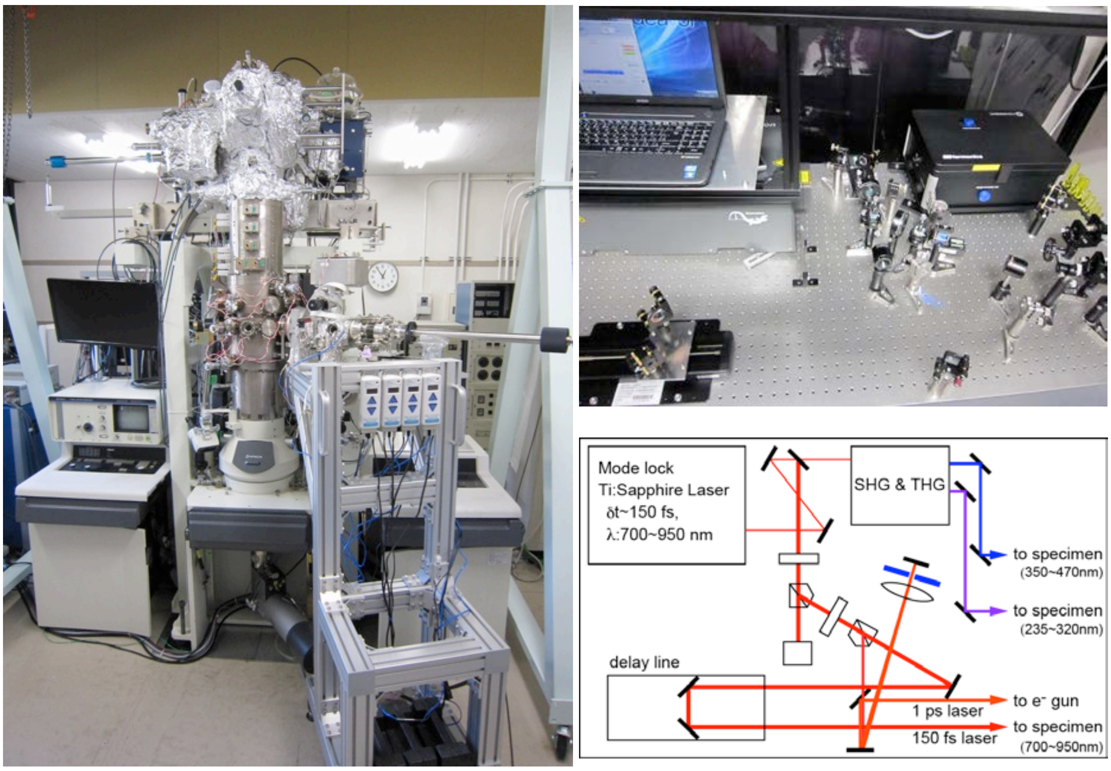

FIG. 1. Photograph of the SP-TEM and the optical system on optical bench. (Left) elevation view of the SP-TEM, (Upper right) femto second pulse laser system for pulse-mode operation for pump-probe measurement in SP-TEM. (Right bottom) schematic diagram of the pulse laser system.