# Scanning SQUID microscopy on compsition-spread NdSrMnO films under irradiation

Hidetaka Sugaya [a,1], Tae-Youb Kim [b], Jun Nishimura [c], Tomoteru Fukumura [c], Masashi Kawasaki [c], Hideomi Koinuma [a], Yoshinori Tokura [d], and Tetsuya Hasegawa [a]

[a] *Materials and Structures Laboratory, Tokyo Institute of Technology, Midori-ku, Yokohama 226-8503, Japan*
[b] *COMET,Advanced Materials Lab.,National Institute for Materials Science,Tsukuba 305-0044,Japan*
[c] *Institute for Materials Research,Tohoku University,Aoba-ku,Sendai 980-8577,Japan*
[d] *Department of Applied Physics,University of Tokyo,Bunkyo-ku,Tokyo 113-8656,Japan*

**Abstract**

Local magnetic properties of composition-spread $Nd_{1-x}Sr_xMnO_3$ (NSMO; $x = 0.4 - 0.6$) films were surveyed by a scanning SQUID microscope under irradiation. We have found that the spontaneous magnetization of the FM phase is significantly enhanced by the laser irradiation ($\lambda = 532$ nm), while the phase boundary is essentially unchanged.

*Key words:* NdSrMnO; scanning SQUID microscopy; composition-spread thin film

## 1. Introduction

A perovskite manganite $Nd_{1-x}Sr_xMnO_3$ (NSMO) exhibits a variety of electronic phases, including ferromagnetic metal (FM), antiferromagnetic insulator (AFI), charge ordered (CO) state, and canted AFI, depending on chemical composition $x$ and temperature. Around $x = 0.5$, where the FM, CO and AFI phases meet, and thus different interactions are competed with each other, the electronic structure might be controllable by applying small perturbations, such as photo-induced carriers.

Previously, we have demonstrated that magnetic phase diagrams of $La_{1-x}Ca_xMnO_3$ [1], $La_{1-x}Sr_xMnO_3$ [2] and NSMO [3] can be rapidly constructed by surveying the magnetic domain structures of corresponding composition-spread thin films with a scanning SQUID microscope. In the present study, we have examined the magnetic properties of NSMO films in composition-spread form under irradiation of visible light. The obtained phase diagram without irradiation is in good agreement with those already established in bulk materials [4]. Photo-irradiation did not essentially affect the phase boundary, but enhanced the magnetic moment is depending on $x$, significantly enhanced up to $40 - 50$ %, depending on $x$.

## 2. Experimental

A composition-spread NSMO film with a thickness of 190 nm was fabricated on a $SrTiO_3$ (STO) substrate, using a laser MBE technique, where the substrate temperature, oxygen pressure and laser power were set to 720 K , 1.0 mTorr, and 230 mW, respectively. The Sr composition $x$ in $Nd_{1-x}Sr_xMnO_3$ was continuously spread from 0.4 to 0.6. For irradiation, we used a Nd:$YVO_4$ laser ($\lambda = 532$ nm). Because the lattice constant of $SrTiO_3$ (0.395 nm) is larger than that of NSMO with $x = 0.4 - 0.6$, the film feels a tensile strain in the in-plane direction.

A scanning SQUID microscope (SSM), equipped with a miniature SQUID ring (10 $\mu$m$\phi$) near the edge of the cantilevar, was used to sense the local magnetic field perpendicular to the film surface, $B_z$, without an

[1] E-mail:hide@rlem.titech.ac.jp

external magnetic field at 3 K. Its spatial and field resolutions are 5 $\mu$m and 50 nT, respectively [5].

## 3. Results and discussion

Figure 1(a) is a line scan profile of $B_z$ along the composition-spread direction of the NSMO film at 3 K without laser irradiation. The figure shows an oscillating structure, demonstrating the presence of magnetic domains, as shown in Fig. 2. The envelope of $|B_z|$ profile is approximately proportional to the magnitude of spontaneous magnetization at each value of $x$. Below $x \sim 0.5$, $|B_z|$ is abruptly increased and reaches to $\sim$40 $\mu$T, while $|B_z|$ is as low as 1 $\mu$T for $x > 0.5$. This result is quite consistent with the bulk phase diagram in which the FM phase is located at $x < 0.5$ [4]. In other words, the phase diagram around $x = 0.5$ is not modified so much by the tensile strain from the substrate.

Figure 1(b) is a $B_z$ profile taken after the irradiation for 90 min. The laser power was 50 mW/mm$^2$. By comparing two curves, it is notable that the $|B_z|$ values below $x = 0.5$ is considerably enhanced up to $\sim$ 50%. Interestingly, the presently observed $|B_z|$ change is a very slow process with a rate of $\sim$0.2$\mu$T/min. Moreover, the phase boundary around $x = 0.5$ does not move at all. Therefore, this phenomena cannot be explained by a simple photo-carrier injection picture, as proposed by Katsu et al. [6, 7] in LSMO/STO.

The mechanism of the photo-induced $|B_z|$ enhancement in Fig. 1 is unknown at present, however, there seems to be two possibilities. Firstly, irradiation may cause drastic rearrangement of magnetic domains, although we have not confirmed this in an experimental sense. For instance, if the domains are enlarged by photons, the stray fields generated from the domain boundaries are, in general, expected to rise. The second possibility is based on the assumption that the FM region of the present film undergoes microscopic phase separation into magnetic and non-magnetic regions. Photo-irradiation may trigger a non-magnetic to magnetic phase transition, as reported in PrCaMnCrO [8].

## 4. Summary

We have investigated the local magnetic properties of a composition-spread NSMO film, using a scanning SQUID microscope. The observed $B_z$ profile well corresponds to the bulk phase diagram, implying that the strain from substrate is negligible in the present NSMO film. Photo-irradiation significantly enhanced $B_z$ of the FM region, but the phase boundary remained unchanged. The reaction is as slow as $\sim$0.2$\mu$T/min for irradiation of 50 mW/mm$^2$, implying that the phenomenon is not understandable within a simple photo-carrier injection scenario.

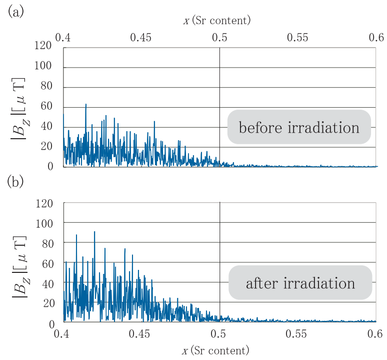


Fig. 1. $B_z$ line profiles of the composition-spread NSMO film before and after irradiation at 3 K.

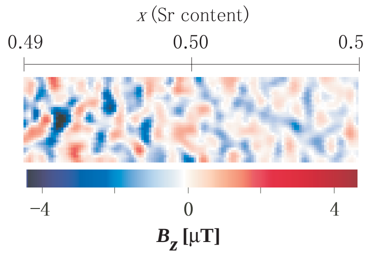


Fig. 2. Two-dimentional magnetic images of NSMO film at 3 K, 400$\mu$m$\times$100$\mu$m.

## References


[1] Y. K. Yoo, F. Duewer, T. Fukumura, H. Yang, D. Yi, S. Liu, H. Chang, T. Hasegawa, M. Kawasaki, H. Koinuma, X. -D. Xiang, Phys. Rev. B**63** (2001) 224421.

[2] T. Fukumura, Y. Okimoto, M. Ohtani, T. Kageyama, T. Koida, M. Kawasaki, T. Hasegawa, Y. Tokura, H. Koinuma, Appl. Phys. Lett.**77** (2000) 3426.

[3] T. Kageyama, T. Hasegawa, T. Koida, M. Ohtani, T. Fukumura, M. Kawasaki, H. Koinuma, Appl. Phys. A**72** (2001) 273.

[4] R. Kajimoto, H. Yoshizawa, H. Kawano, H. Kuwahara, Y. Tokura, K. Ohyama, M. Ohashi, Phys.Rev.B**60** (1999) 9506.

[5] T. Morooka, S. Nakayama, A. Odawara, M. Ikeda, S. Tanaka, K. Chinone, IEEE Trans. Appl. Supercond.**5** (1999) 3491.

[6] H. Katsu, H. Tanaka, T. Kawai, Appl. Phys. Lett.**76** (2000) 3245.

[7] H. Katsu, H. Tanaka, T. Kawai, J. Appl. Phys.**90** (2001) 4578.

[8] Y. Okimoto, Y. Ogimoto, M. Matsubara, Y. Tomioka, T. Kageyama, T. Hasegawa, H. Koinuma, M. Kawasaki, Y. Tokura, Appl. Phys. Lett.**80** (2002) 1031.