Optica Applicata, Vol. LII, No. 1, 2022
DOI: 10.37190/oa220105

Polarization multiplexed bit data recording to submicron-particles-arrayed optical storage

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In this study, a submicron-particles-arrayed optical storage disk was fabricated by the spin coating method. Moreover, we have formed a multi-valued pit by irradiating linearly polarized laser beams at multiple angles (0° and 90°). The optical setup has the semiconductor laser ($\lambda = 637$ nm) for reconstructing and the SHG-YVO$_4$ laser ($\lambda = 532$ nm) for recording. The optical setup measured the submicron-particles-arrayed optical storage as a confocal image by 2D scanning with a motorized stage.

Keywords: submicron-particle, confocal microscope, optical storage.

1. Introduction

Today, the amount of information handled is exponentially increasing with the development of information-related equipment. Under such circumstances, the optical disk storage is indispensable as a device for recording a large amount of information. There are several ways to improve this performance. There are methods such as bit reduction [1, 2], polarization multiplexed recording [3–5], multiplexing of recording wavelength [6, 7], and lamination of recording layers [8–12]. There are also optical memories that use technologies such as holograms. Our laboratory has been currently investigating an optical storage system using submicron particles [13–19]. We have verified a jitter-free single -layered storage disk system [20–26] using 500 nm-diameter particles. The particles are arranged on a linear groove [27]. We described a method of data storage using submicron particles as recordable pits with a confocal microscope [28, 29].

In this paper, we propose a new design of multi-valued encoding mass storage without jitter. Submicron particles are arranged on a plane and multi-valued recording is performed for this. To this goal, we have adopted two approaches: one is the buffer ring, which is a gap between the submicron particles. This is called buffering, which is a non-photosensitive area; the other is polarization-multiplexing bit-data recording for multi-valued encodes. Since the buffer ring enhances the particle's shape contrast, for data pickup the confocal microscope can also measure submicron particles under its spatial resolution. Polarization multiplex recording can be realized by irradiating a single particle with a linearly polarized laser beam at multiple angles. We verified the multi-level-pit by writing two bit-data on one particle. The storage system proposed in this research and the conventional optical memory are briefly compared. Conventional optical discs use physical irregularities and differences in the reflectance of materials as pits. In this research, the submicron-particle is used as a pit, a clock signal is extracted from the shape signal of the submicron particle itself. Regeneration signal is generated from that signal, thereby realizing storage without jitter. This submicron particle jitter-free data storage system is a concept that can be expanded to a jitter-free microhologram system using submicron particles.

2. Experimental procedure

2.1. Sample preparation

The first section describes how to fabricate submicron-particle-arrayed optical storage disks and their particle's characteristics. Figure 1 illustrates a process to fabricate the submicron-particles-arrayed optical storage disk. A solution containing submicron particle was dropped onto the substrate by spin coating: particles are arranged on a cleaned glass substrate. We used Fluoresbrite® Polychromatic Red Microspheres (manufactured by Polysciences, Inc.). The 500 nm polystyrene particle contains xanthene dyes. It has strong absorption, both in a 525 nm excitation wavelength and in a 565 nm fluorescence wavelength. The spin rate was 1st: 500 rpm for 30 sec, 2nd: 1000 rpm for 30 sec. The sample was dried up naturally.

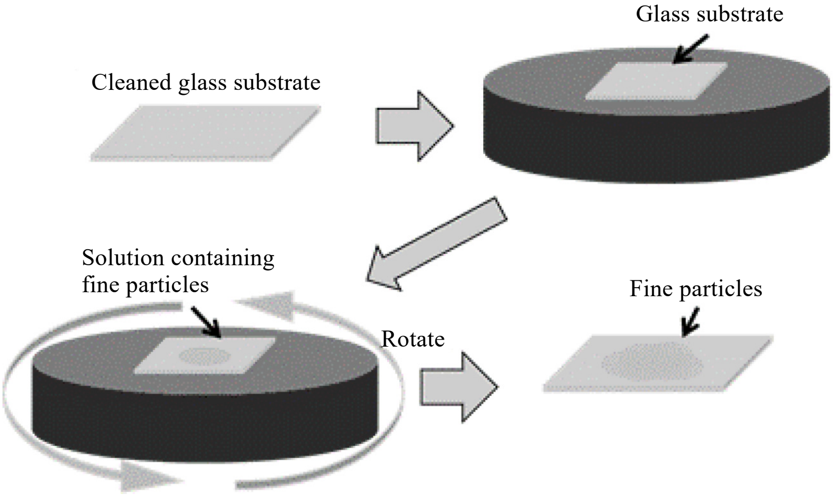

Fig. 1. The fabrication process of submicron-particles-arrayed optical storage by spin coating.

2.2. Experimental setup

The second section describes the confocal optical system for bit data recording/reading. Figure 2 presents a schematic of the optical setup for the submicron-particles-ar-

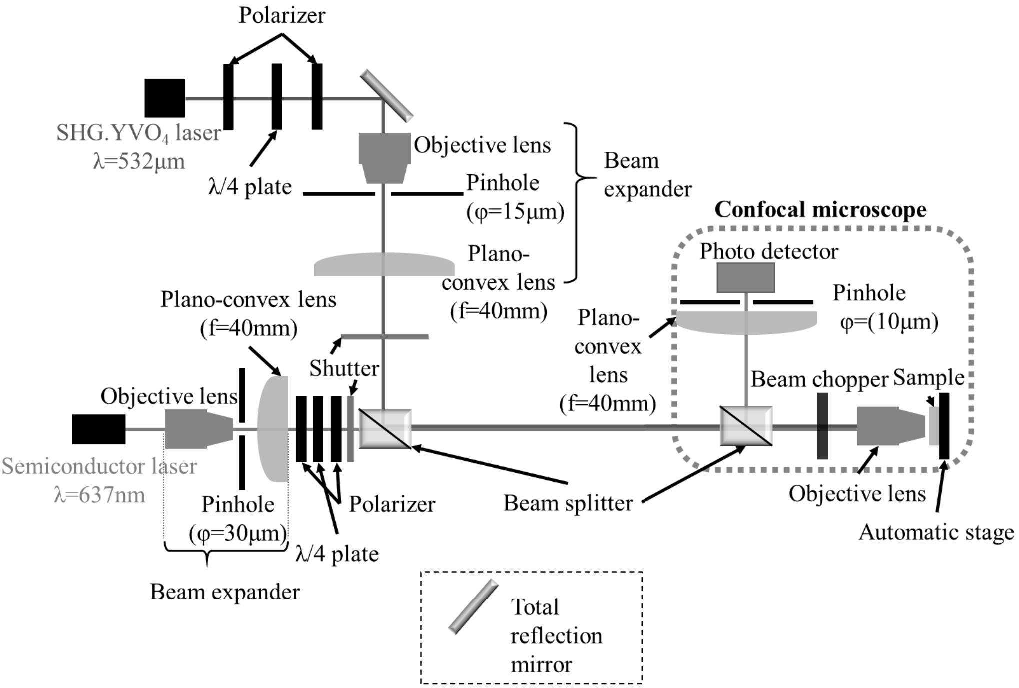

Fig. 2. Recording/reproducing optical system incorporating a confocal microscope.

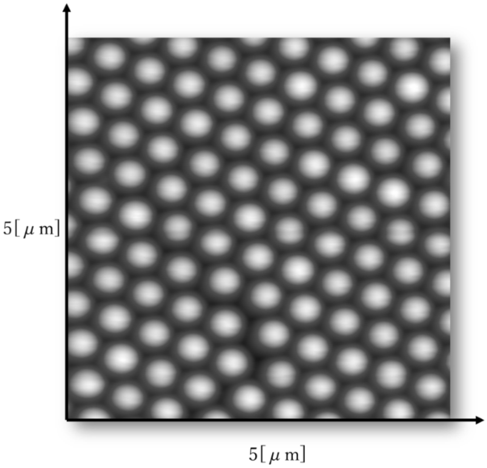

Fig. 3. Optical axis resolution of the confocal microscope when a mirror is installed instead of the sample.

rayed optical storage. The data recording and reading apparatus with the reflection -type confocal scanning microscope has two laser light sources: a semiconductor laser (λ = 637 nm) and a SHG-YVO_4 laser (λ = 532 nm), respectively. The semiconductor laser beam (λ = 637 nm), which passes through the beam expander, focuses on the sample surface through the objective lens (NA = 0.9). The optical system measured the confocal reflection signal from the surface of the sample. The axial spatial resolution of the conventional confocal microscope was pre-measured by scanning a mirror instead of the disk sample. Figure 3 shows a confocal signal along the optical axis. The axial resolution, which was defined as the full width at half maximum (FWHM), measured about 700 nm. It was much larger than the diameter (500 nm) of the particles. However, even the conventional microscope can resolve consecutive particles. This is because the buffer ring will help to improve the S/N of the reflected signal and the resulting contrast of the confocal image.

2.3. Experimental method

The third section describes the experiments of actual sample preparation, polarization multiplex recording, and data reconstruction. Figure 4 shows submicron-particles-arrayed optical storage with non-photosensitive buffer ring (of tens of nanometer width) around particles. In this study, the optical setup irradiated with xanthene-based submicron particles of two different linearly polarized beams (0°, 90°). We verified that each polarized laser beam induces nonlinear dielectric polarization components, and the reconstructing signal can be generated from the measured image. The 2D scanning of the optical storage appearance measured the image of three aligned submicron particles selected. Linearly polarized laser beam illuminated the submicron particle for

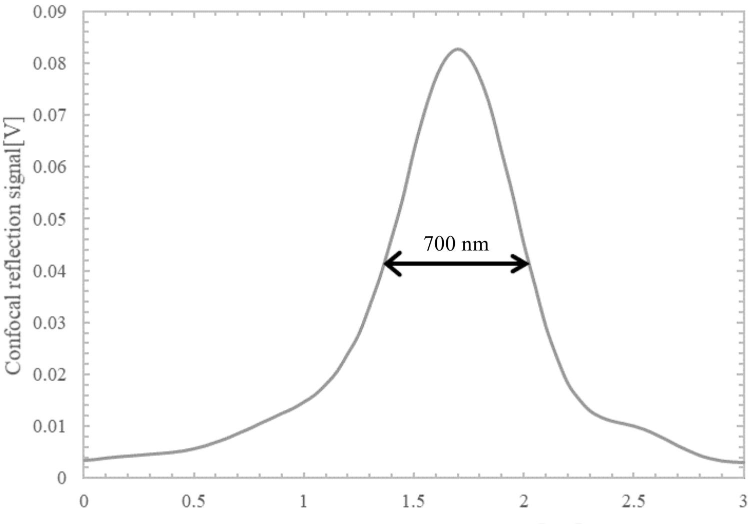

Fig. 4. AFM measurement image of submicron-particles-arrayed optical storage.

Table. Details of polarization multiplexed recording on micro-particles-arrayed storage

Submicron-particles position	Left	Center	Right
Laser power (0°)	20 μW	20 μW	None
Laser power (90°)	11 μW	None	
Laser irradiation time	30 sec		
Laser frequency	4000 Hz		

recording. The Table shows the details of the recording. After that, the sample was 2D scanned in the same range as the surface measurement image before recording, and the surface signal was measured and imaged.

3. Results

In the final section we describe the performance of the polarization multiplexed recording for multi-valued encoding. For the clock signal, we set an arbitrary threshold in the confocal reflection signal in the scan region. The signal generates the non-return -to-zero. We obtained the bit decision signal by taking the difference between the signals before and after recording. Figures 5**a** and 5**b** shows the images before and after recording with the measurement's laser at 0°. Figures 5**c** and 5**d** similarly shows the image at the measurement's laser at 90°. The part surrounded by the dotted line is the

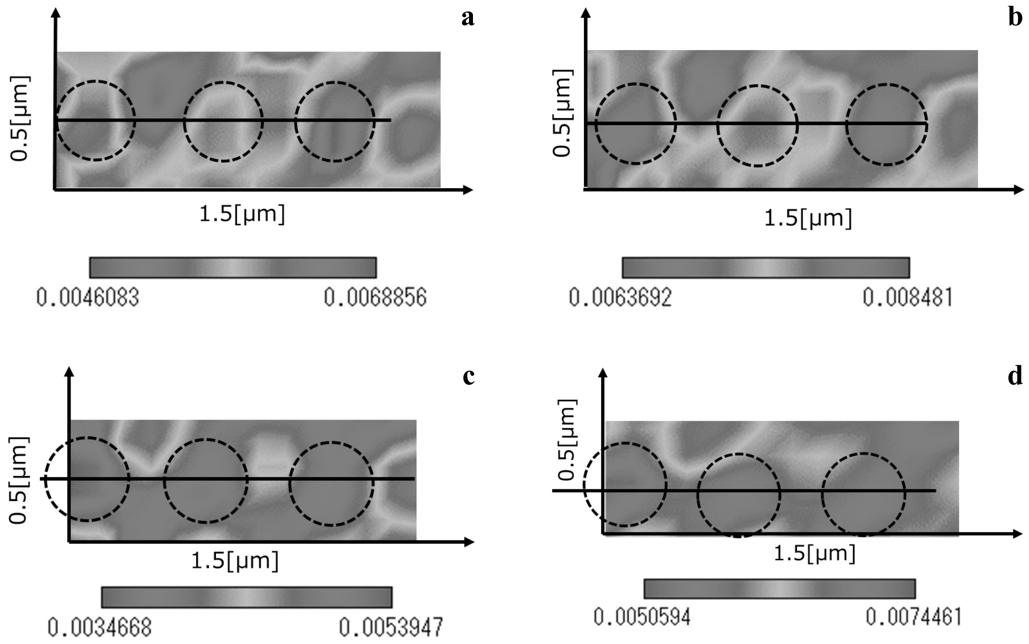

Fig. 5. Sample measurement image and scan area when the measurement laser angle is 0°: before (**a**) and after (**b**) recording. Sample measurement image and scan area when the measurement laser angle is 90°: before (**c**) and after (**d**) recording.

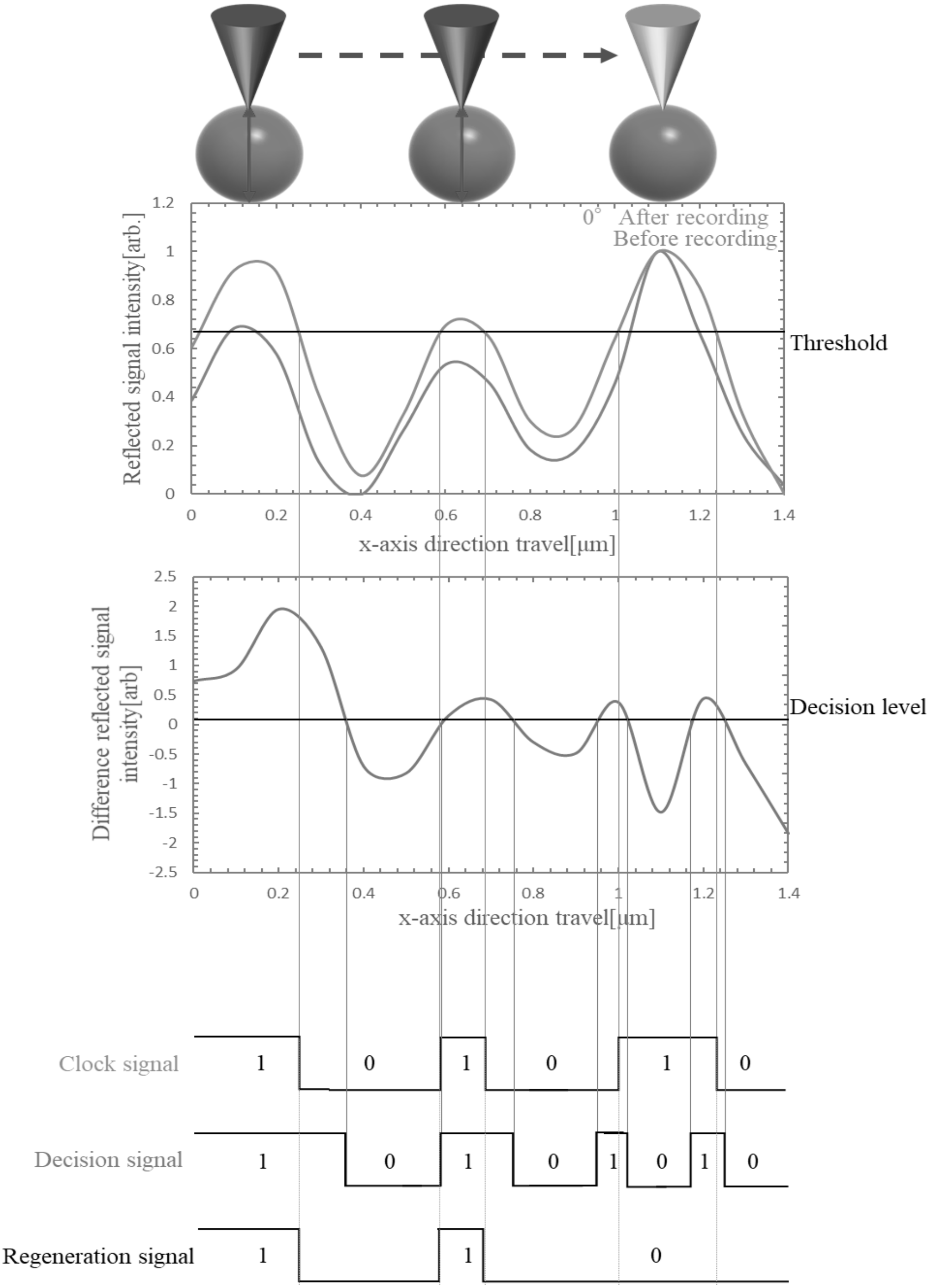

Fig. 6. Measurement laser generation of the clock signal, bit decision signal, and regeneration signal from scan area before and after recording at 0°.

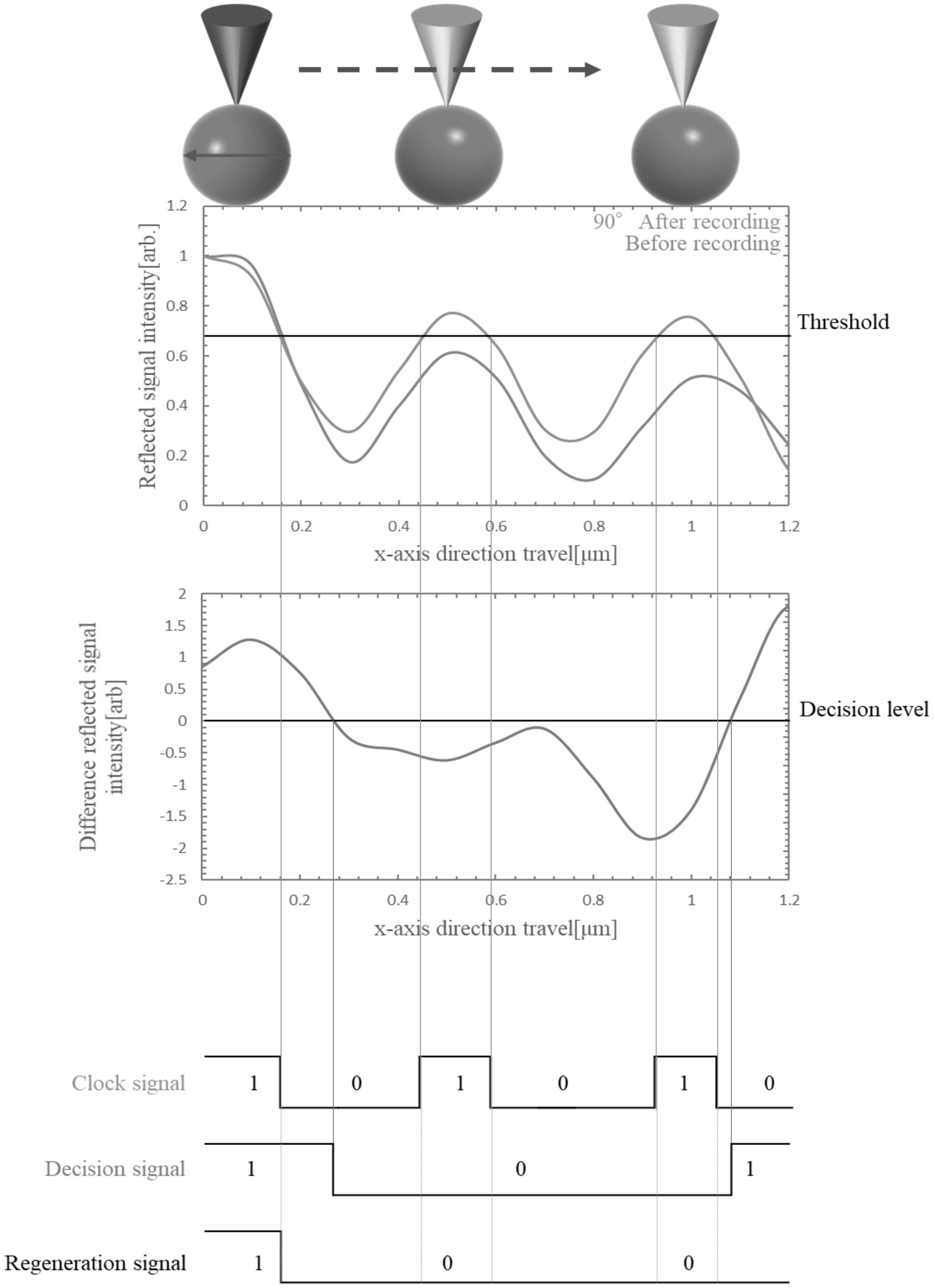

Fig. 7. Measurement laser generation of the clock signal, bit decision signal, and regeneration signal from scan area before and after recording at 90°.

position of the submicron particle, and the black straight line is the scan area for extracting the primary signal. Figures 6 and 7 show images obtained by extracting one -dimensional signals from the scan area and generating clock signals, bit decision signals, and regeneration signals, respectively. Figures 6 and 7 are explained in order from the top. The top shows the positions of recorded and unrecorded submicron particles. It is a recorded submicron particle whose dark green laser is irradiated. The following graph shows the surface measurement signal before and after recording. An arbitrary threshold is set on this graph. The clock signal in the bottom figure corresponds to this. The following graph shows the difference between the surface measurement signal before and after recording. The decision level is set on this graph. The decision signal in the bottom figure corresponds to this. In the figure at the bottom, the clock signal and the decision signal are AND to generate a regeneration signal. In Fig. 7, there is a part where one clock signal has a two-bit decision signal. However, the part of the decision signal was set to 0 due to an error in the focal position during measurement.

4. Conclusions

To summarize the results, the regeneration signal was (1 1 0) when the linear polarization of the measuring laser was 0°, and the regeneration signal was (1 0 0) when the linear polarization of the measuring laser was 0°. In other words, two digital levels were recorded and reproduced for one submicron particle. Therefore, the success of multi-valued -submicron-particles by polarization multiple recording was confirmed. The S/N ratio was about 6 dB when calculated from Fig. 5 of the experimental results. In the method of this report, the data density and S/N ratio depend on the size of the submicron particle and the NA of the objective lens. The theoretical data density was about 7.76 Tbit/mm^2 based on Fig. 4 and the experimental results that double the recording are possible on one submicron particle.

Acknowledgement
This work was supported in part by a grant in aid for fundamental scientific research from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

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Received December 21, 2020