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XY-Stage-Based Electron-Beam Recorder for the Single-Carrier Independent Pit-Edge Recording Radial Partial Response Format

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An electron-beam recorder in an XY-stage-based architecture was developed for mastering optical disks. The recorder uses the single-carrier independent pit-edge recording radial partial response (SCIPER/RPR) format. An electron beam is irradiated onto a master disk on continuously moving X and Y stages that are controlled so as to draw circular traces in sine and cosine waveforms against time, respectively. High-accuracy pit recording was realized using electron-beam deflection with feedforward correction of stage positioning error. A 25-Gbit/in^2 SCIPER/RPR read-only-memory test disk with an alternating pit-array pattern was fabricated using the recorder. The pit-edge accuracy was evaluated from a scanning-electron-microscope image of the pattern. The obtained accuracy values were 1.6 nm (σ) for mark pitch, 3.5 nm (σ) for track pitch, and 3.8 nm (σ) for index position, which are good values for 3-level pit-edge modulation with 30-nm steps. [DOI: 10.1143/JJAP.41.1714]

KEYWORDS: optical disk, electron beam, mastering, SCIPER, XY stage, accuracy, continuous drawing

1. Introduction

The method of combining multi-level recording with partial response detection,[1] such as single-carrier independent pit-edge recording radial partial response (SCIPER/RPR),[2–4] has attracted interest due to its potential to realize a read-only-memory (ROM) optical disk with a density of over 25 Gbit/in^2 by using only a single recording layer.[2] This format is anticipated to have an advantage in its increased recording density, blue readability, and replication feasibility in the stamping process. Figure 1 shows an example of the 25-Gbit/in^2 SCIPER/RPR format pattern. In this figure, we suppose that a light spot of $\lambda = 405$-nm wavelength is focused with an $\mathrm{NA} = 0.85$ objective lens, then the estimated spot diameter is ~ 390 nm. Each pit edge is modulated into three levels, and a light spot catches two pit edges at the sampling point, as shown in the figure, then the readout signal separates into five levels ($3 \times 2 - 1 = 5$). Minimum pit length is 132 nm in this 25-Gbit/in^2 format. We can read out the recorded data with a conventional type of optical pickup head by using a blue light with a sampled servo technique. This is another advantage of this format.

We are targeting in our project the fabrication of optical disks having a density of over 40 Gbit/in^2 by using modified format of this SCIPER/RPR. To achieve such a density in this format, the modulation step length will have to be shortened to ~ 15 nm and the partial response method will also be used for the tangential direction. The accuracy required between each of two neighboring tracks, i.e., index position error that is allowed for the RPR detection, is roughly estimated to be ~ 5 nm to avoid carrier mixing in the readout signal,[4] because the carrier signal caused by the index position error must be kept lower than the modulation step. A request has been made to align the pit pattern with a mark pitch accuracy of ~ 1.5 nm for the tangential direction, i.e., trace direction, since the jitter should be less than 10% of the modulation step. Moreover, in our project we are aiming to draw wide range of pit patterns for use in a real optical disk player. These accuracy values seem considerably severe compared with the values in the conventional XY-stage-based static electron-beam lithography system, for which the overlay accuracy is of the order of $20 \sim 50$ nm ($M + 3\sigma$) ($6 \sim 17$ nm in σ value) for the drawing range of more than 5 inches.[5] Therefore, a request has been made to manufacture a new electron-beam lithography system that is specially designed for optical disk mastering of such high accuracy and over a wide drawing range. Compared to the previously reported electron-beam mastering systems for optical disks,[6–8] this mastering system has unique features in its XY-stage-based construction and index-position control.

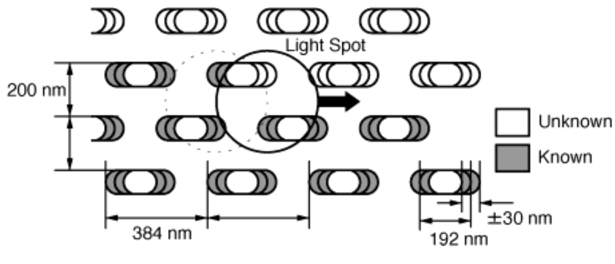

Fig. 1. SCIPER/RPR format pattern with alternating pit array for 25 Gbit/in^2 density. High accuracy of the pit positioning is necessary in both the tangential and radial directions for the RPR readout of the data on two tracks scanned at the same time.

2. System Construction

Figure 2 shows the schematic structure of our XY-stage-based mastering system. The stages are set in an evacuated chamber. The stage position is detected by a laser interferometer pair having 0.077-nm digital resolution and a 40-kHz detection band width. A circular trace is generated as sine and cosine waveforms by a trace generator also having a 0.077-nm resolution. Then, the X and Y stages are controlled so as to draw the trace accurately; the X stage moves in the sine waveform with time, while the Y stage moves in the cosine waveform. The stage positioning errors, i.e., the X and Y errors from the ideal circular trace, are kept within 5 μm during the mastering at the trace velocity of 10 mm/s. The electron beam is irradiated onto the master disk on these continuously moving stages. The residual stage positioning errors are de-

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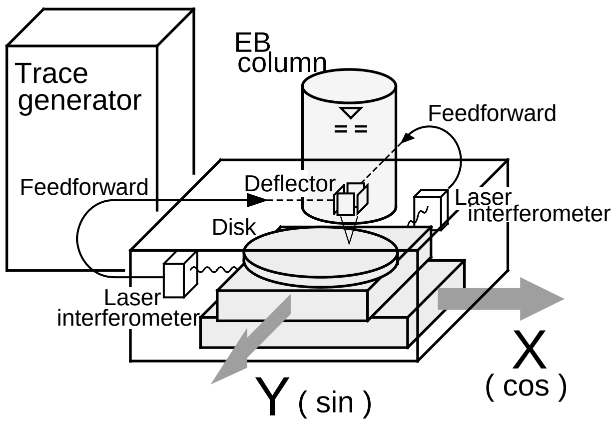

Fig. 2. Schematic of XY-based mastering system. The circular trace and pit patterns are generated by a software formatter. The stage position is detected by a laser interferometer pair with 0.077-nm resolution. The mechanical error is corrected by electron-beam deflection.

tected by the laser interferometer pair and then corrected by using electrostatic beam deflection. This XY-stage-based system has an advantage in that the stage position is directly and accurately detected by the laser interferometers with conventional optics; therefore, the beam-deflection error correction has high accuracy. This system also has an advantage in its flexibility; the stage traces can be selected as long as the trace selected is smooth and continuous. The blanking control of the electron beam has a time resolution of 160 MHz, synchronized with the trace generation. The pit patterns are generated by a software formatter, which also allows flexible pattern control of the beam blanking. Using this flexible system, we fabricated a SCIPER test disk.

3. Processing and Evaluation

Figure 3 shows an scanning-electron-microscope (SEM) image of a 25-Gbit/in^2 SCIPER/RPR ROM disk pattern (with an alternating pit array) fabricated by the XY-stage-based mastering system. The resist resin used was ZEP-520. The thickness of the resist layer was 200 nm. The substrate was a 5-inch Si wafer. In the figure, the lower half of the SEM image is of a single-carrier pattern, while the upper half is of a 3-level pit-edge modulation pattern. The displacement of the pit positions was evaluated from the SEM image in the single-carrier pattern region. Figure 4 shows the histogram plots of the mark pitch, track pitch, and displacement error of the index pit edge of the pattern shown in Fig. 3. The evaluated mark pitch, track pitch, and index position errors on the pattern are also shown schematically. Each histogram plot shows a Gaussian-like distribution. The obtained standard deviation values (σ) were 1.6 nm for mark pitch, 3.5 nm for

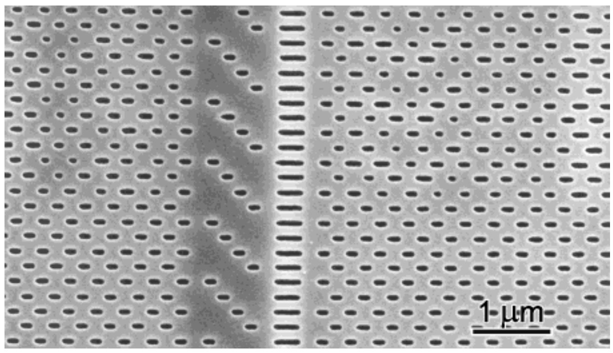

Fig. 3. An SEM image of a 25-Gbit/in^2 SCIPER/RPR ROM disk pattern with alternating pit array on a Si wafer fabricated using the XY-stage-based mastering system. The lower side of the image is of a single-carrier pattern, while the upper half is of a 3-level modulated pattern. The servo patterns in the frame header area shows the stair-like features.

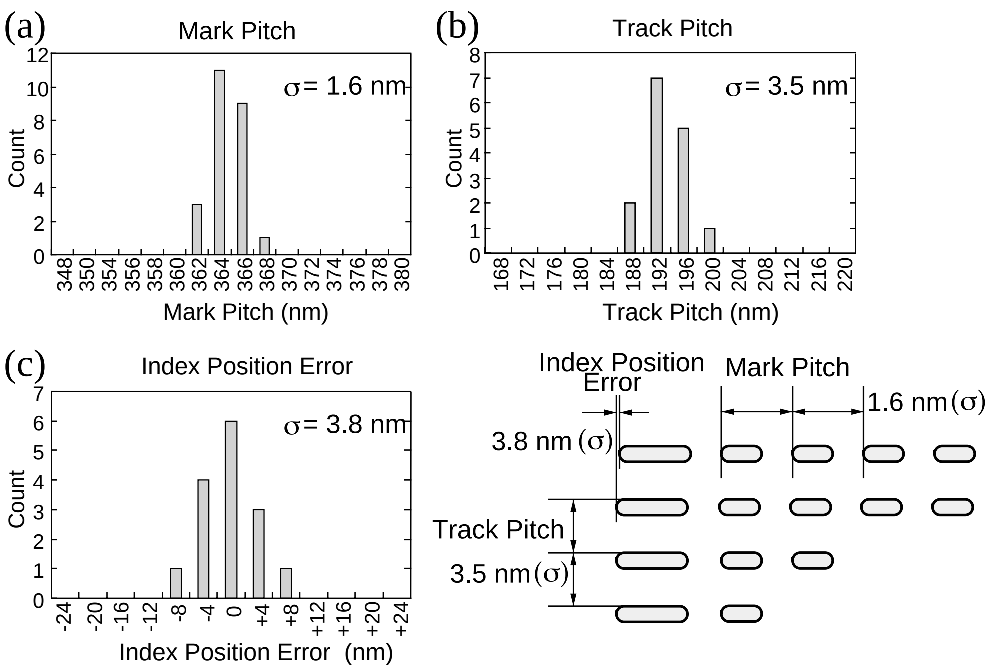

Fig. 4. Histogram plots of the (a) mark pitch, (b) track pitch, and (c) positioning error of the leading edge of the index pits (arrayed long mark). Obtained accuracy values are (a) 1.6 nm (σ), (b) 3.5 nm (σ), and (c) 3.8 nm (σ), respectively.

track pitch, and 3.8 nm for index position error. These deviation values are fairly good and smaller when compared with the pit-edge-modulation step of 30 nm in this 25-Gbit/in^2 format, but severe for the partial response detection, since the accuracy necessary for the 25-Gbit/in^2 format is even higher and any errors must be smaller than 3 nm (σ) if we consider the double-track readout in the SCIPER/RPR. The mark pitch errors (1.6 nm (σ)) are smaller than the index position errors (3.8 nm (σ)), since the index position errors are mainly due to low-frequency vibrations ($\sim$50 Hz) having a period that is 300 times longer than the mark pitch, while the mark pitch errors are mainly due to high-frequency beam blanking (15 kHz) noises or roughness of the resist. The slow-varying change of the mark pitch due to the low-frequency vibrations is not seen in the short-range SEM image shown in Fig. 3.

Compared to conventional XY-stage-based electron-beam writers for which the positioning errors are often evaluated in $M + 3\sigma$ values (overlay accuracy),[5] this system is free from the averaged displacement error M (parallel shift of the whole pattern), since the optical disk patterns are circular and cyclic. The remaining pit positioning errors seem to be resulting from the presence of undetected mechanical vibration around the stages, chambers, electron-beam-gun column, and even possibly electrical noises. We will accordingly increase the system accuracy further by reducing these vibration and noises.

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