Precise formation of fine pits on birefringent film for multi-level optical data storage

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Abstract: We have proposed and demonstrated a multi-level optical data storage by changing the pit depths of birefringent film. Multi-level pits with the width of 1μm and with various depths were formed on a liquid crystalline polymer film, and the phase difference between orthoganal polarizations was confirmed to be proportional to the depth of pits.

1. Introduction

In the present optical data storage, the binary coding is used, in which the mark and null levels corespond to the high and low levels of reflected light. To increase the memory density further beyond the future high-density optical data storage sysytems like near-field data storage[1],[2], a multi-level data storage will be an effective coding technique.

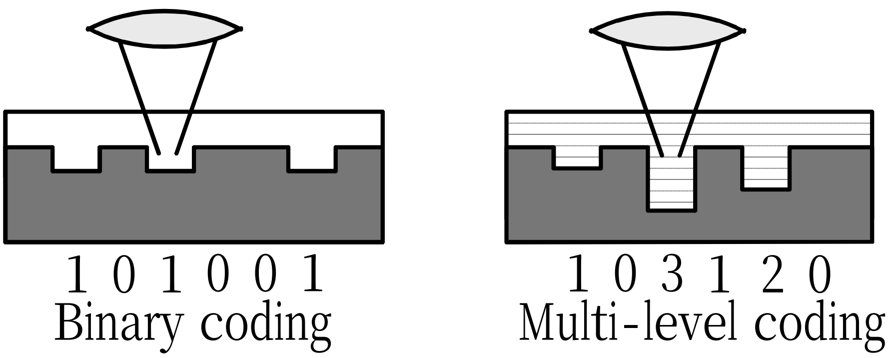

Fig.1: Principle of multi-level optical data storage

Thus far, several methods of multi-level data storage[3] have been proposed and demonstrated. However, these methods utilize only the multi-level change of reflected light intensity, and so the number of levels has been limited less than eight levels due to the limitation of

CNR. In this report, we propose and demonstrate a multi-level optical data storage utilizing the phase difference of orthogonal polarizations of reflected light. Since the phase difference ranges from -$\frac{\pi}{2}$ to $\frac{\pi}{2}$, the number of levels is expected to be larger than ten. In addition, if the multi-level of reflected intensity is used in combination with this method, the number of levels will be increased further due to the large area of two dimensional coding space.

2. Principle of multi-level optical data storage

If the linearly polarized light is incident on a pit formed on a birefringent film and the orientation of principal axis of birefringence is angled to the direction of polarization, the polarization state of output light changes from the linear polarization due to the birefringence. Since the phase difference is linearly proportional to the thickness of birefringent film (depth of pit), a multi-level coding on the phase difference will be possible. Thus we formed some pit patterns on a birefringent film and measured the phase difference between orthogonal polarizations.

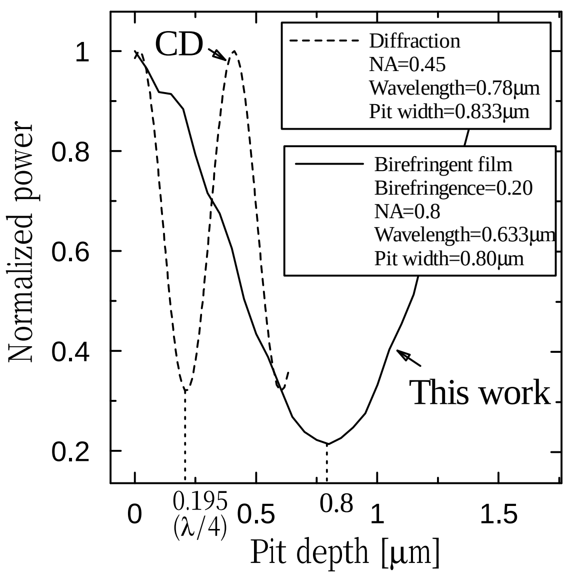

Fig.2: Comparison of detected light intensity vs the pit depth

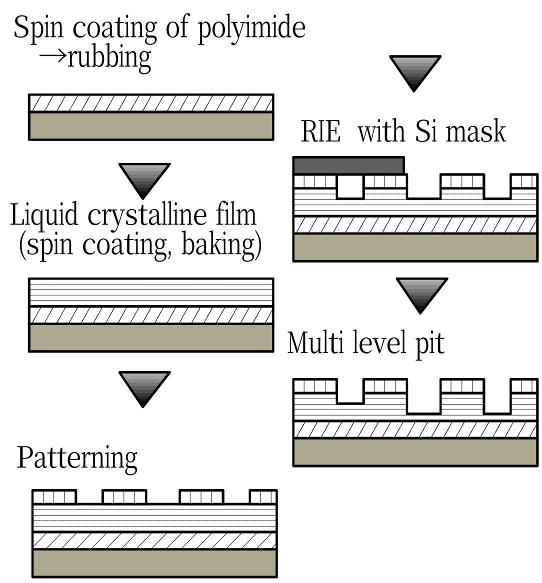

Fig.3: Fabrication process

To compare the tolerance of pit depth, we calculated the detected light intensity agaist the pit depth of conventional CD and this method, and the results are plotted in Fig.2. Since the phase difference is detected in this method, we assumed that the phase difference was converted to the intensity change using an interferometer. The birefringence was assumed to be 0.20, which is the same value as that of liquid crystalline polymer film used in this study. It can be seen from Fig.2 that the tolerance of pit depth of this method is much larger than the simple multi-level coding utilizing the depth change of pit in the conventional disk systems.

3. Fabrication

We used a liquid crystalline polymer film (birefringence is 0.20) for the base material of optical data storage. The liquid crystalline film was formed by spin coating on a polyimide film of 0.8μm thick, which acted as the orienting layer, and the LC polymer was solidified into its glassy state after the alignment process at 220°C. SiO_2 glass plate with 0.5mm thickness and 75mm diameter was used as the substrate. After the baking, photoresist was formed on the film by spin coating. A stripe pattern with the width of 1 μm was formed on a photoresist by the photolithography technique, and the pattern was etched down to the liquid crystalline polymer film by the reactive ion etching using oxigen gas. In the RIE process, first a part of the area of the substrate was covered by a Si mask during the dry etching, and the Si mask was shifted step by step, as shown in Fig.3. This process is equivalent to the change of etching time for individual pits. Then a stripe pattern with various depth was successfully obtained. The thickness of the film was $1.4\mu m$ and the depth ranged from $0\mu m$ to $0.8\mu m$.

4. Measurement setup

The orientation and the phase difference between orthogonal axes of birefringence were measured by comparing the state of polarization of input linearly polarized light and that of output elliptically polarized light. The state of polarization of the output light was measured by the setup shown in Fig.4. The orientation of linear polarization of input light was angled at 45° to the orientation of LC polymer. The direction of rotation of elliptical polarization was measured by inserting a quarter-wave plate in front of the analyzer. Although the reflection type pickup should be used for the practical use, we measured the phase difference of transmitted light for the simplicity of measurement setup.

In this measurement setup, a very small spot was achieved using a high NA lens (NA=0.80). Thus a pit of the smallest width of 0.63μm can be measured by this setup. Fig.5 shows an example of measured SOP (state of polarization). This result was measured by detecting the output power against the rotation angle of analyzer. Since the output power is expressed by the sinusoidal function with respect to the rotation angle of analyzer, we fitted the measured data to the sinusoidal function using the least squares fit to improve the accuracy of measurement.

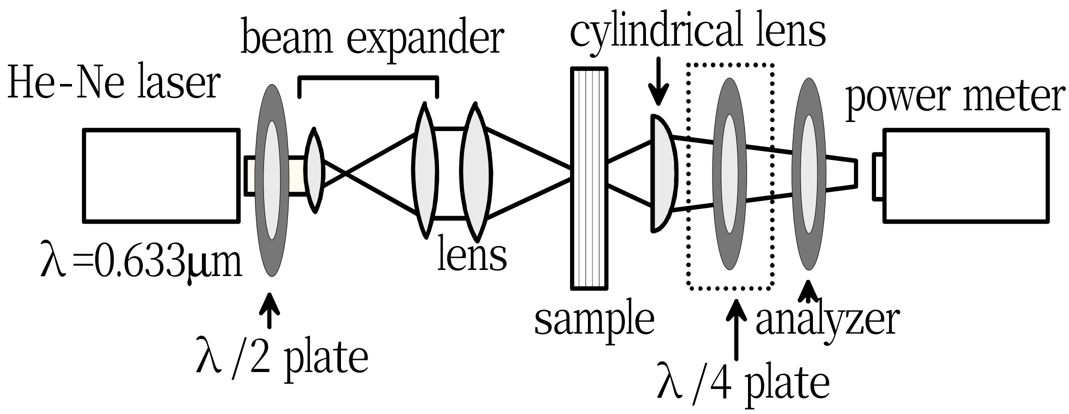

Fig.4: Measurement setup of polarization state

5. Experimental results

Some memory disk samples with different widths and pit depths were prepared and measured. The relation between the measured phase difference and the pit depth is shown in Fig.6. Prior to this measurement, the relation between the etching time and the etched depth was measured, and the etched depth was evaluated from the etching time in Fig.6. It can be seen that the change of phase difference decreases with the decrease of thickness of birefringent film, and the slope against the thickness corresponds to the birefringence of 0.2, which is the same value as the theoretical birefringence of liquid crystalline polymer film. Thus the multi-level coding utilizing the pit depth formed on a birefringent film was successfully demonstrated.

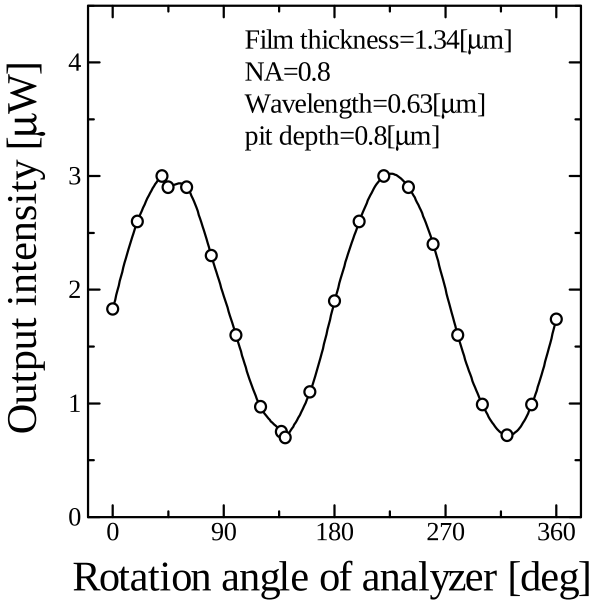

Fig.5: Measured polarization state

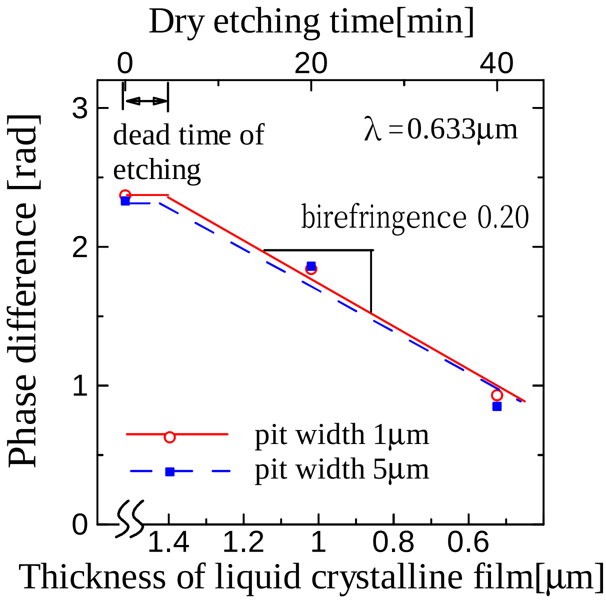

Fig.6: Measured phase difference between orthogonal polarization

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