17p-D5-2

Super-resolution Complex Amplitude Reconstruction of Nanostructured Binary Data with Pattern Matching

Shinji Ishikawa and Yoshio Hayasaki

Center for Optical Research and Education (CORE), Utsunomiya University
E-mail: ishikawa_s@opt.utsunomiya-u.ac.jp

1. Introduction

The amount of processed data has been continuing to increase day by day. The demands for high-speed, high-capacity data storage are also increasing. The demands on optical recording media are the same as those on other kinds of media, but it is well-known that, in principle, the recording density is limited by the optical diffraction limit. Therefore, new technologies the recording density to improve the density, including volume optical recording and reading methods using holography [1], as well as two-dimensional optical recording and reading method using super-resolution near field structures [2].

In this paper, we investigate a method for identifying nanostructures having an elemental size with several tens of nanometers smaller than the diffraction limit by using an interference microscope with a pattern matching method.

It is technically challenging to determine the minimum size in identifying nanostructures using propagation light. It is well-known that propagating light fails to reveal most of the information about nanostructures, and the amount of missing information increases as the elemental size of the nanostructures decreases. However, small remaining difference between the propagation light components reflected by nanostructures are detectable, depending on the signal-to-noise ratio of the whole imaging system, and if we know the one-to-one relation between these differences and the original pattern, that is to say, under a special constrain condition and given prior information, we will be able to identify the nanostructures.

The complex amplitude obtained by interference microscopy gives more useful information for identifying the nanostructures. This identification is an important issue for reconstructing the data in optical storage. We propose a new method of optically reconstructing binary data using complex amplitude images as information for using an interference microscope. The nanostructure we treat here is a binary structure formed by a pit or land having a size of several tens of nanometers. We examined the size dependency of binary data reconstruction using the finite difference time domain method (FDTD) and light propagation based on the spatial frequency filtering technique representing imaging optics.

2. Reconstruction of binary nanostructures

A pit (convex structure) expresses a binary digital value of 1 (high) and the absence of a pit, i.e., a land, expresses 0 (low). A linear arrangement of pits and lands expresses multiple bits. Figure 1 shows a binary nanostructure representing the 4-bit binary digital data 1101. The pit width and height are denoted as w_p and h_p, respectively. A target binary nanostructure is observed with an interference microscope, and a complex-amplitude image is obtained. The target binary nanostructure is reconstructed with the 1:*N* matching method, in which *N* complex-amplitude templates corresponding to *N* binary data patterns are prepared in advance using an interference microscope simulated in a computer. The template that has the most similarity to the observed complex amplitude image is selected from the *N* templates. Finally, the binary data reconstructed.

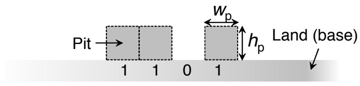

Fig. 1 Binary nanostructure representing digital data.

3. Evaluation of reconstruction performance using bit error rate (BER) in the presence of electronic noise

The characteristics of the binary data reconstruction in the presence of random noise were evaluated. The interference microscope was simulated by using the FDTD method for calculating the light propagation near the nanostructure and spatial filtering based on the fast Fourier transform for simulating the microscope imaging system. The light source was a laser with a wavelength λ of 400 nm. The numerical aperture of the objective lens was NA = 0.85. The pit and land consisted of aluminum. A complex amplitude image was obtained by analyzing interference images captured by an image sensor using the phase shifting method with four steps. It is postulated that white Gaussian noise with mean 0 and variance σ^2, is present in the fringe images. Figure 2 shows the bit error rate (*BER*) versus the signal-to-noise ratio (*SNR*) when the number of pits and the width w_p and height h_p was varied.

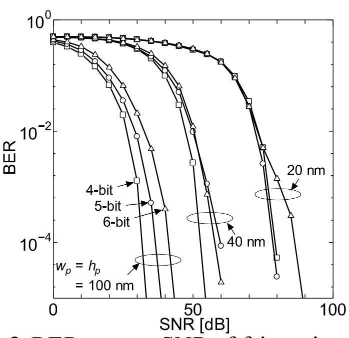

Fig. 2 *BER* versus *SNR* of fringe images

4. Conclusions

We demonstrated a new optical reconstruction method of binary data formed by nanostructures smaller than the diffraction limit using an interference microscope. At a result, in reconstruction of 6-bit binary structures, we demonstrated BER < 10^{-4} when $w_p = h_p$ = 40nm and SNR = 60dB.

References

[1] P. J. van Heerden, "Theory of optical information storage in solids," Appl. Opt., **2**, 393-400 (1963).

[2] J. Tominaga, T.Nakano and N. Atoda, "An approach for recording and readout beyond the diffraction limit with and Sbthin film," Appl. Phys. Lett., **73**, 2078-2080 (1988).