Hierarchical Optical Memory System Using Near- and Far-field Accesses

Makoto Naruse
National Institute of Information and Communications Technology, 4-2-1 Nukui-kita, Koganei, Tokyo 184-8795, Japan

Takashi Yatsui
Japan Science and Technology Agency, 687-1 Tsuruma, Machida, Tokyo 194-0004, Japan

Wataru Nomura and Motoichi Ohtsu
University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 184-8795, Japan

Abstract: We propose a hierarchical optical memory system in which near-fields and far-fields read detailed dipole distributions and features within a region-of-interest, respectively. With hierarchical coding, near- and far-field accesses are associated with different hierarchical information.

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1. Introduction

Ultrahigh-capacity optical data storage is an important technology. Various methods to increase the storage density have been pursued, such as shortening the operating wavelength [1]. With such methods, the storage density is still bound by the diffraction limit of light. One technique to overcome this limitation, which we make use of in our proposed system, is optical near-fields [2]. These high-density optical memories, however, need certain seeking or scanning mechanisms, which might be a problem, for instance, when searching terabyte- or petabyte-scale memories.

In dealing with this problem, we first note that information has hierarchy in terms of its meaning or quality, such as "*abstract*" and "*detailed*" information, "*low*" and "*high*" resolution information, and so forth. Similarly, as discussed below, we can find physical hierarchy in the different modes of light propagation. For example, in a near-field, a spatial distribution of the dipole moments is obtained, whereas in a far-field, the macroscopic features of the dipole moments are obtained. We associate these hierarchies in the system demonstrated in this paper, that is, a hierarchical optical memory system having both near- and far-field readout functions with a simple digital coding scheme. As schematically shown in Fig. 1, in the far-field mode, low-density, rough information is read-out, whereas in the near-field mode, high-density, detailed information is read-out.

2. Logical model of hierarchical coding

The two-layer hierarchical memory in this paper is explained using the notations *far-code* and *near-code*. The *far-code* depends on the array of bits distributed within a certain area and is determined logically to be either ZERO or ONE. Each *far-code* is comprised of multiple smaller-scale elements, whose existence is determined by the *near-code*. To obtain such information hierarchically, we introduce the following simple logical model.

Consider an $(N+1)$-bit digital code, where N is an even number. Now, let the *far-code* be defined depending on the number of ONEs (or ZEROs) contained in the $(N+1)$-bit digital code:

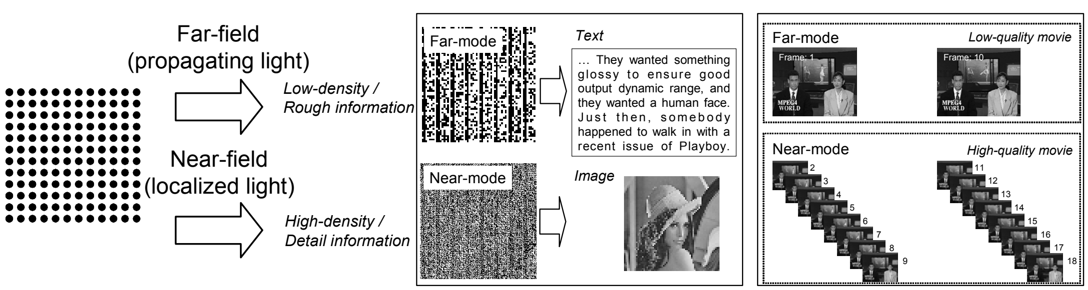

Fig. 1 Hierarchical optical memory using near- and far-field accesses.

$$far-code = \begin{cases} 1 & \text{If the number of ONEs} \geq \text{N/2} \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

The (N+1) digits provide a total of 2^{N+1} possible different permutations, or codes. Here, we note that half of them, namely 2^N permutations, have less than N/2+1 ONEs among the (N+1) digits (i.e., *far-code* = 1), and the other half, also 2^N permutations, have more than N/2+1 ZEROs (i.e., *far-code* = 0). In other words, 2^N different codes could be assigned to two (N+1)-bit digital sequences so that their corresponding *far-codes* are ZERO and ONE, respectively. We call this (N+1)-bit code a *near-code*.

In Fig. 2, example *near-codes* are listed when N = 8. The correspondence between 2^N original codes and the (N+1)-bit *near-codes* is arbitrary. Therefore, we need a table-lookup when decoding an (N+1)-bit *near-code* to the original code. The example *near-codes* shown in Fig. 2(a) are listed in ascending order, but other lookup-tables or mappings are also possible.

Fig. 2(b) schematically demonstrates example codes in which a 9-bit *near-code* is represented in a 3 × 3 array of circles, where black and white mean ONE and ZERO, respectively. Here, (1) if the number of ONEs in the *near-code* is larger than five, then the *far-code* is ONE; and (2) if the number of ONEs in the *near-code* is four or less, then the *far-code* is ZERO.

Suppose, for example, that the *far-code* stores text data and the *near-code* stores 256-level (8-bit) image data. Consider a situation where the *far-code* should represent an ASCII code for "A", whose binary sequence is "0100001". Here, we assume that the gray levels of the first two pixels, which will be coded in the *near-code*, are the same value. (Here, they are at a level of "92".) However, the first two *far-codes* are different (ZERO followed by ONE). Referring to the rule shown in Fig. 2(a), and noticing that the first *far-code* is ZERO and the *near-code* should represent "92", the first *near-code* should be "001101010". In the same way, the second *near-code* is "110001011", so that it represents the level "92", while its corresponding *far-code* is ONE.

3. Physical model of the near- and far-codes

The *far-code* is determined based on the rule given by eq. (1), which depends on the number of ONEs coded in the *near-code*. Here, we employ a simple physical model where the *near-code* is represented by an array of dipole moments. As schematically shown in Fig. 3(a), dipole moments are distributed in an *xy* plane, where an (N+1)-bit code is assigned in an equally spaced grid. The electrical field at position $\boldsymbol{r}$ in Fig. 3(a) is given by

$$E(\boldsymbol{r}) = \sum_{i,j} E_{i,j} e^{-i\omega t + ik|\boldsymbol{r}-\boldsymbol{s}_{i,j}|} \frac{1}{|\boldsymbol{r}-\boldsymbol{s}_{i,j}|} \tag{2}$$

where ω is the operating frequency, k is the wave number, and $\boldsymbol{s}_{i,j}$ represents the position of a dipole specified by indexes i and j [3]. The existence of the dipole at the position $\boldsymbol{s}_{i,j}$ is given by the *near-code* as

$$E_{i,j} = \begin{cases} 0 & \text{nearcode}(i,j) = 0 \\ E_0 & \text{nearcode}(i,j) = 1 \end{cases} \tag{3}$$

Suppose that the pitch of adjacent dipoles is given by b. Here, if we assume that b<<1<<r, then eq. (2) is simplified

(a)

Given 8-bit code	***Near-code*** (***far-code* = 0**)	***Near-code*** (***far-code* = 1**)
0	000000000 (0)	000011111(31)
1	000000001 (1)	000101111(47)
2	000000010 (2)	000110111(55)
⋮	⋮	⋮
92	001101010 (106)	110001011(395)
93	001101100 (108)	110001101(397)
94	001110000 (112)	110001110(398)
⋮	⋮	⋮
253	111001000 (456)	111111101(509)
254	111010000 (464)	111111110(510)
255	111100000 (480)	111111111(511)

(b)

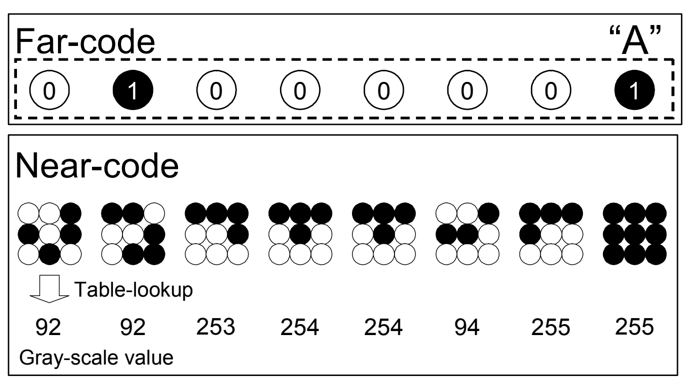

Fig. 2 Example of logical model for the *near-code* and *far-code*. Here, the original 8-bit information is coded differently in *near-code* depending on its corresponding *far-code* which is either ZERO or ONE.

to

$$E(\mathbf{r}) = E_0 \frac{e^{-i\omega t + ikr}}{r} \sum_{i,j} \text{nearcode}(i, j) \tag{4}$$

which means that the electrical field intensity at position $\boldsymbol{r}$ is proportional to the number of ONEs given by the *near-code* in that area.

4. Experiment and Simulation

For the experiment, an array of particles was made, in which 100-nm-diameter Au particles were distributed over a SiO_2 substrate. Each group of 3 × 3 Au particles with 300-nm pitch represented a *near-code*, and adjacent *near-codes* were located with 2-μm spacing. An SEM picture is shown in Fig. 3(b-1). These particles were fabricated by using electron-beam (EB) lithography using a Cr buffer layer (a liftoff technique), which allowed Au formation on the SiO_2 substrate with features having a diameter down to 35 nm, as shown in Fig. 3(b-2). Although final experimental results are still pending, basic simulations were performed assuming ideal isotropic metal particles to see how the scattering light varies depending on the number of particles for the *far-code* using a Finite Difference Time Domain simulator (Fujitsu Inc. Poynting). Fig. 3(c) shows calculated scattering cross sections as a function of the number of particles. The assignment of particle(s) in the grid is also shown. A linear correspondence to the number of particles was observed.

5. Summary

In summary, we propose a hierarchical optical memory system in which near-fields are used to read detailed dipole distributions, whereas far-fields are used to detect features within a region-of-interest. An experimental device and simulations were also shown. With hierarchical coding, near- and far-field accesses are associated with different hierarchical information, which should help overcome problems involved in searching huge memory spaces. General design of the logical model and applications will also be pursued as well as physical implementations.

References

[1] For example, http://www.blu-ray.com/

[2] M. Ohtsu, K. Kobayashi, T. Kawazoe, S. Sangu, and T. Yatsui, "Nanophotonics: design, fabrication, and operation of nanometric devices using optical near fields," IEEE J. Select. Topics Quantum Electron. **8**, 839-862 (2002).

[3] M. Ohtsu and K. Kobayashi, *Optical Near Fields* (Springer, 2004), Chap. 4.

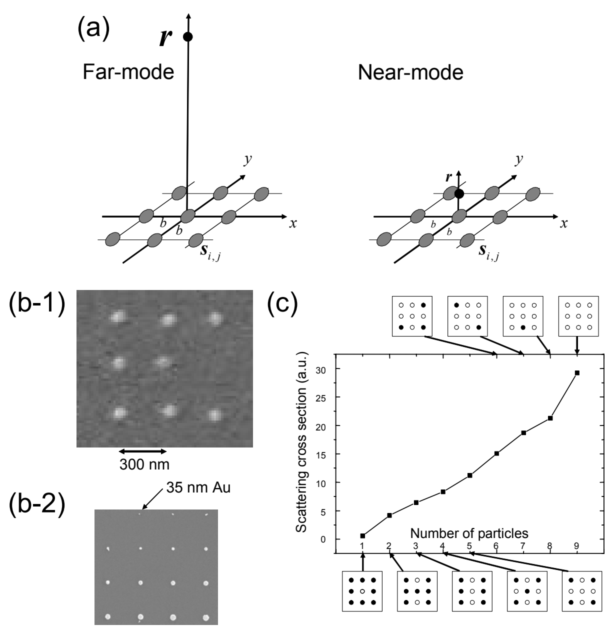

Fig. 3 (a) Physical model. (b) Au particle arrays for the experiment. (c) Simulation of the *far-code*.