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Enhanced resolution induced by random silver nanoparticles in near-field optical disks

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Abstract

The super-resolution near-field structure (super-RENS) is a high-density near-field optical data storage medium which can achieve superior spatial resolution beyond the diffraction limit. Our previous studies found that enhanced local optical intensity occurred at the near fields of super-RENS disks, and the nonlinear near-field optical enhancement is related to the localized surface plasmons of silver clusters dissociated from the AgO_x layer in the super-RENS disks. In this paper, we studied the near-field and far-field properties of AgO_x-type super-RENS with different distributions of silver nanoparticles using finite-difference time-domain (FDTD) simulations. Highly localized enhancements are found between adjacent silver nanoparticles in the near fields. The far-field signals of different silver nanoparticles distributions confirm the super-resolution capability of AgO_x-type Super-RENS disks, and a simplified Fourier optics model is used to describe the relation between highly localized near-field distributions and enhanced resolution of far-field signals.

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1. Introduction

Near-field optical data storage technique was first demonstrated by Betzig et al. [1,2] on multilayered Pt/Co magneto-optical thin films using a near-field scanning optical microscope (NSOM). High spatial resolution recording was accomplished by using a sub-wavelength aperture at the tapered tip of an optical fiber operated in the near-field region. Though the diffraction limit is successfully overcome, it is difficult to precisely

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control the distance between probe and medium less than a wavelength and to simultaneously maintain a high scanning rate. The recording speed of near-field optical recording using NSOM is still around μm/s, which is quite slow comparing with the recording speed of a commercial digital versatile disk (DVD), which is higher than 3.5 m/s. Terris et al. [3] used solid immersion lens (SIL) to reduce the mechanical damage which comes from the near-field optical fiber probe, and to achieve higher recording speed. Although the focused spot size is decreased to 317 nm, the control of near-field distance between the SIL recording head and the recording medium remains major difficulties for commercial applications.

In 1998, the multilayer structure, polycarbonate/SiN(170 nm)/Sb(15 nm)/SiN(20 nm)/GeSbTe(15 nm)/SiN(20 nm), was demonstrated to overcome the diffraction limits and the SiN/Sb/SiN layer was named super-resolution near-field structure (super-RENS) [4–7]. The carrier-to-noise ratio (CNR) is more than 10dB with 90 nm recording marks. The thin Sb film above the phase-change medium, GeSbTe, in the super-RENS replaces the fiber probe in the near-field optical recording system. Subsequently, the AgO_x-type super-RENS [8] was developed for higher carrier-to-noise ratio (CNR). For 90 nm recording marks, the CNR reached to 15 dB. To understand the optical properties of the AgO_x-type super-RENS, we have used a tapping-mode tuning-fork NSOM in transmission mode to measure the near-field optical images [9–11], and found that highly localized near-field intensity enhancements are occurred around the super-RENS. Our previous studies have also shown that enhanced local optical intensity exhibits at the near field, and the unusual optical effect is related to the localized surface plasmon of silver clusters dissociated from AgO_x [11–16]. To study the relation between random silver nanoparticles and nonlinear localized enhancements, the near-field optical fields of AgO_x-type super-RENS with silver nanoparticles embedded in AgO_x layer were calculated by two-dimensional finite-difference time-domain (FDTD) simulations [11,15,16]. The silver nanoparticles and the localized evanescent waves around silver nanoparticles could act as virtual near-field optical probes and the disadvantages of the conventional SNOM were solved by the super-RENS technology.

Metallic nanoparticles of subwavelength size exhibit plenty of optical phenomena related to geometry-dependent surface plasmon resonances. The enhanced electric fields are confined within a few nanometers near the surface of nanoparticles. The resonances are due to dipolar or high-polar collective oscillations of conduction electrons in particles [17,18]. In previous studies, we found that the super-resolution efficiency of the AgO_x-type super-RENS is related to the localized surface plasmon of silver clusters dissociated from the AgO_x layer and the complicated interactions between the nonlinear near-field optical enhancements and the subwavelength recording marks [11–16]. The highly enhanced localized surface plasmons improve the reading efficiency, but the relation between the nonlinear near-field optical effects and the detective far-field signals is still not clear. To further understand the unusual optical effect of the AgO_x-type super-RENS, we used 2D FDTD numerical simulation method to study the near-field properties of the AgO_x-type super-RENS disks with different random distributions of silver nanoparticles. Since the detectable optical signals are the far-field intensities, the near-to-far field transformation [19] was used to realize the relations between near-field enhancements and far-field variations of the AgO_x-type super-RENS disks with different distributions of embedded silver nanoparticles.

2. Simulation model

The numerical method is a two-dimensional FDTD with periodic boundary condition and perfect matched layers, which have the advantages of reduced memory requirement in computation, and simple process in handling the complex structure. The structure of the super-RENS disk was cover glass/ZnS–SiO_2 (20 nm)/AgO_x (15 nm)/ZnS–SiO_2 (20 nm)/GeSbTe (16 nm), as shown in Fig. 1. The incident laser light was Gaussian distributed with wavelength of 650 nm, and the numerical aperture of the lens was 0.85. The refractive index of ZnS–SiO_2 and AgO_x layer was 2.07 and 2.7,