High Density Recording and Plasmon Technologies in Phase Change films

JUNJI TOMINAGA

Laboratory for Advanced Optical Technology (LAOTECH)
National Institute of Advanced Industrial Science & Technology (AIST)
1-1-1 Higashi, Tsukuba, 305-8562, Japan

Phase change optical recording has gradually progressed up to the storage density of 5 GB with DVD system, and soon reaches more than 20 GB by using blue laser beam. More over the 50GB, however, the system will be close to the optical diffraction limit, and new other techniques have to be applied. Using optical near-field towards the super-density optical data storage is expected as one of the promising core technologies; but, many difficulties are still remained and unsolved, especially on the problems of high-speed readout for the flying lens and head. As an alternative method, using super-resolution mask technique was also proposed in combination with optical near-field effect, and it was named "super-RENS (super-resolution near-field structure)." Through the research for the last three years, several important relationship between near-field recording and surface and local plasmons generated over tiny marks beyond the diffraction limit may play an important role in future high-density optical recording. In this paper, several characteristics of near-field recording and readout by using super-RENS are described, and novel techniques generated through the research are introduced.

KEYWORDS: Phase change recording, near-field recording, high-density optical data storage, super-RENS

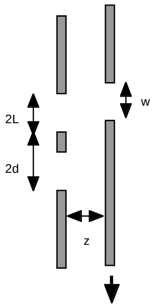
1. INTRODUCTION

According to the development of high-definition-digital-broadcasting TV, available information is getting bigger day by day. Data storage technologies involving hard disk and optical disk have always been replaced by new technologies with higher capacities. In optical disk, soon blue laser system will update the current red laser system, resulting in 20 GB and more capacities in the near future. Replacing the blue and approaching sub-terabyte region has already been investigated, overcoming the optical diffraction limit by optical near-field.[1-3] Using optical near-field is one of the promising candidates for the future data storage because its characteristics are not limited by the diffraction theory, but the size of the aperture which is emerged at the tip of the probe; thus the near-field can readout the size of molecular level theoretically. However, retrieving stable and rigid near-field signals is very difficult because of its strong dependence of the spacing between the tip and recording medium within 50 nm under a high-speed disk rotation system.[4-5] So far, several ideas have been proposed with a hard disk type slider head within a small aperture, with solid immersion lens, and with super-resolution mask layer.[6-8]

Super-resolution near-field structure (super-RENS) was developed by our group in 1998, combining with super-resolution mask technique and near-field optics.[9,10] In our first experiment, we demonstrated the readout resolution of less than 100 nm, and in the second approach 60-nm resolution was achieved by 635-nm wavelength and lens NA 0.6. In 1999, new super-RENS disk was also developed by using silver oxide (AgOx) and its light scattering characteristics with Sharp Corp..[11] First two years research of super-RENS quite inclined towards revealing the basic properties and understanding near-field recording. However, through the research, very interesting world of near-field optics and phase change recording has gradually cleared.[12,13] In this paper, I describe not only near-field and surface plasmons generated over phase change recording marks, and its scattering, but also several new approaches towards photonic devices.

2. HIGH-DENSITY RECORDING AND SURFACE PLASMON GENERATION

As it is well known, current optical recording and readout depends on far-field optics, and an mark signal is readout by the basic theory of the separation and coverage of 0th and +/- 1th order diffraction; and it determines the diffraction limit (ϕ = λ/NA). In near-field readout, of course, we have to retrieve much smaller marks under the base of the diffraction theory. Thus, the signal cannot be obtained anymore by the separation of 0th and +/- 1th order diffraction in the pupil. Well, how can super-RENS read such tiny marks ? The understanding key is optical coupling of optical near-field and surface plasmons covering with the recorded marks. The Fourier optics determines the modulation function of two slits problem is determined as shown. [14]



$$f(x,z=Z)=\int_{-\omega/2\pi c}^{+\omega/2\pi c} dk_x \exp(-2\pi i k_x)\exp[-2\pi i(k^2-k_x{}^2)^{1/2}(Z-\varepsilon)]$$

$$\times \int_{-\infty}^{\infty} dk'_x\, 4E_0 \cos k_x' d\, \frac{\sin 2\pi k_x L}{2\pi k_x}\exp[-2\pi i(k^2-k_x'^2)^{1/2}\varepsilon]$$

$$\times \frac{\sin\pi(k_x-k_x')w}{\pi(k_x-k_x')}\exp[-2\pi i(k-k_x')X]$$

The first integration is carried out in the limit of spatial frequency between $-\omega/2\pi$ and $+\omega/2\pi$. However, the second term's integration range is not but in infinitive. Therefore, in the higher frequency, exp term changes non-propagating mode (here, *kx* is taken along the slit direction). This terms couples with the first term and the near-field terms (higher frequency term), becoming the far-field signal. ε = z is the spacing between two slits, and the higher term rapidly reduces with ε. However, considering only increasing the second term's integration does not improve the near-field signal because the term effect is not so large in comparison with the value in the diffraction limit. The first super-RENS trials were carried out without such consideration.

In order to improve super-RENS signal intensities, we tried to apply surface and local plasmon effect. Effectively using and generating the plasmons may increase the signal intensity by the factor of 7 or 10. However, replacing Sb layer into Ag cannot generate the surface plasmons because of miss matching of *kx*. Attenuated total reflection (ATR) method such as SIL is the typical device to generate surface plasmons;[15] but the device cannot be inserted in the optical disk. Instead, we focused on using the mark trains as a 1-dimensional grating in the laser spot. To generate the plasmons, we have to prepare for one dielectric layer with a positive dielectric constant ε (square of refractive index, n^2), and adjacent metallic layer with negative constant. The crystalline state of phase change film ($n_{GeSbTe\text{-}crystal}$ = *3.7-4.68 i*, thus ε_{crystc} = *-7.8-35.2 i*), and the amorphous shows ε_{amo}=*12.6-20.3 i*. Therefore, the crystalline marks satisfies the condition. Also, confining the electrical field in x-direction (along the mark trains), we have to satisfy imaginary $kz = [\varepsilon_1(\omega/c)^2 - (\omega/c)^2(\varepsilon_1\varepsilon_2/(\varepsilon_1+\varepsilon_2)]^{1/2}$. By the grating effect, we can further increase *kx* by reducing the grating pitch beyond the diffraction limit and obtain imaginary *kz* (See Fig. 1). This fact means that phase change marks can accumulate the surface plamsons, and the smaller the mark size, the more plasmons are concentrated in the laser spot.

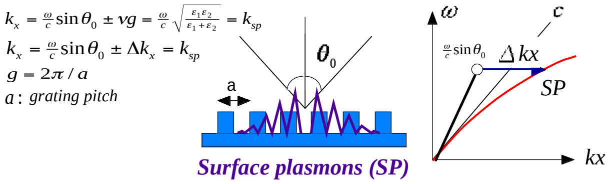


Fig.1 Relationship between the surface plasmons and grating pitch

Fig.2 and Fig. 3 are FDTD computer simulation results of the surface plasmons generated over the small marks. In Fig. 2, alternative mark patterns consisting of Ag-AgOx, and GeSbTe-crystal-amorphous in Fig. 3 are calculated respectively. The incident light polarization is along the patterns, and 635-nm wavelength is used. In both cases, for relatively long marks, two plasmon peaks are allowed at the mark edges, and the plasmons are concentrated in the centers as the size is smaller and smaller. The intensity of the plasmons depends on the negativity of ε, and the Ag scattering centers show much stronger plasmon field than that of GeSbTe.

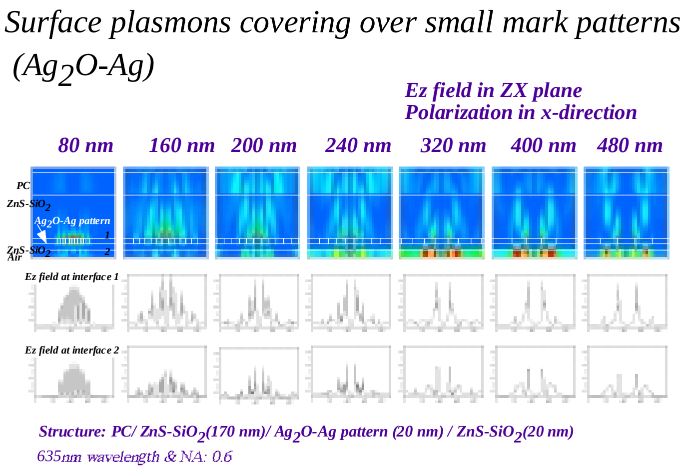


Fig. 2 Plasmon field intensity depending on mark pattern size in Ag-AgOx system

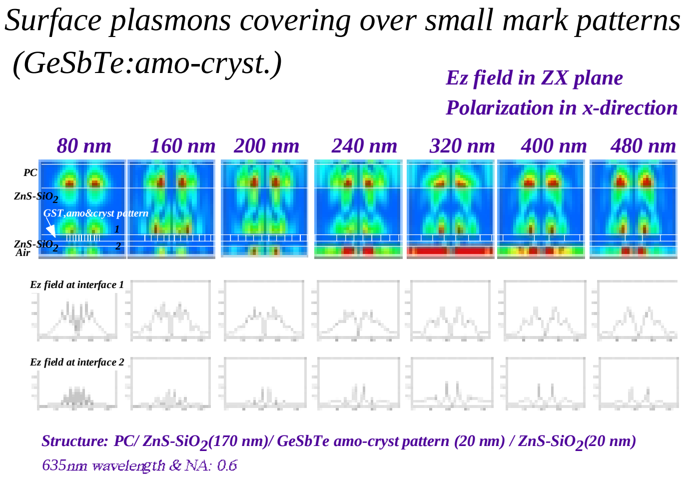


Fig. 3 Plasmon field intensity depending on mark pattern size in crystal-amorphous GeSbTe system

According to Figs. 2 and 3, it is easy to understand that the near-field interaction and coupling together of Ag cluster and GeSbTe recording pattern generate very strong far-field scattering as the readout signals.

3. TOWARDS PLASMONS DEVICES

The simulation results were in agreement with the actual experimental results presented in the international near-field optics conference 6 (NFO-6) in 2000. Interestingly, phase change recording marks can be used as a plasmon reservoir. Recently we proposed one application of the plasmon coupling and scattering in super-RENS optical disk towards photonic amplifyer, "local plasmon photonic transistor." The principle is very simple. Focusing two laser beams in the super-RENS disk, and one beam is slightly modulated and another is used only for generating a light-scattering center in the AgOx film. After small mark trains are recorded, and then two laser beams are crossed. As tuning the laser beam position, the transmitted signals from the modulated laser beam are amplified by adjusting another laser power (sees Fig.4 and 5). It is understood that recording marks have an important role in the signal gain in "local plasmon photonic transistor."[12]

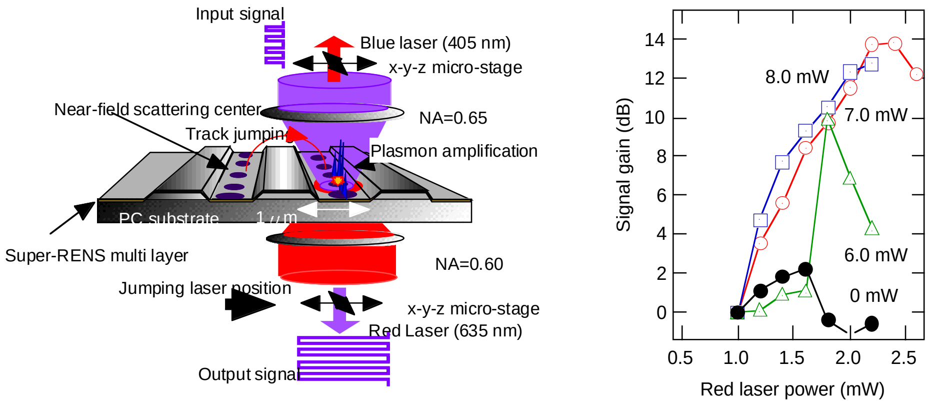


Fig. 5 The principle and experimental setup for local plasmon photonic transistor, and the relationship between signal gain and recorded mark size. 200-nm mark trains were recorded by several laser powers, 0, 6.0, 7.0 and 8.0 mW. The blue laser was modulated between 0.5 and 0.7 mW at 15.3 MHz.

4. CONCLUSIONS

Optical near-field, surface and local plasmon effects in super-RENS optical disks were described. Optical phase change films have a very important role in generating and enhancing the signals beyond the diffraction limit size. Also, as the other application, local plasmon photonic transistor was introduced.

References

1. E. Betzig , S. Grubb, R Chichester, D. Digiovanni and J. Weiner, *Appl. Phys. Lett*., **63**, 3550 (1993).
2. E. Betzig , J. Trautman, T. Harris, J. Weiner and R. Kostelak, *Science*, **251**, 1468 (1991).
3. S. Hosaka, T. Shintani, M. Miyamoto, A. Hirotsune, M. Terao, M. Yasuda, K. Fujita and S. Kammer, *Thin Solid Films*, **273**, 122 (1996).
4. H. Ukita, Y. Katagiri and H. Nakada, *SPIE* **1449** Optical Data Storage, 248 (1991).
5. H. Yoshikawa, T. Ohkubo, K. Fukuzawa, L. Bouet and M. Yamamoto, *Appl. Opt*., **38**, 863 (1999).
6. B. Terris, H. Mamin and D. Ruger, *Appl. Phys. Lett*., **65**, 388 (1994).
7. B. Terris, H. Mamin and D. Rugar, *Appl. Phys. Lett*., **68**, 141 (1996).
8. I. Ichmura, S. Hayshi and G. .Kino, *Appl. Opt.*, **36**, 4339 (1997).
9. J. Tominaga, T. Nakano, and N. Atoda, *Appl. Phys. Lett*., **73**, 2078 (1998)
10. J. Tominaga, H. Fuji, A. Sato, T. Nakano, T. Fukaya, N. Atoda, *Jpn. J. Appl. Phys*., **38**, 4089 (2000)
11. H. Fuji, J. Tominaga, L. Q. Men, T. Nakanao, H. Katayama, and N. Atoda, *Jpn. J. Appl. Phys*., **39**, 980 (2000).
12. J. Tominaga, C. Mihalcea, D. Buechel, H. Fukuda, T. Nakano, N. Atoda, H. Fuji, T. Kikukawa, *Appl. Phys. Lett*., **78**, 2417 (2001).
13. D. Buechel, C. Mihalcea, T. Fukaya, J. Tominaga and N. Atoda, "Investigation of sputtered silver oxide depositions for the super-RENS high density optical data storage application," Material Research Soc. Symposium, April 19, 2001, Calfornia, US.
14. J. Vigoureux, C. Girard and D. Courjon, *Opt. Lett*., **14,** 1039 (1989).
15. H. Raether, *Surface Plasmons*, Spring-Verlage, Berline, 1988.