Investigation on the mechanism of AgO_x film super resolution near-field structure

Yang Guo¹, Hai Ming¹, Lin Tang¹, Pei Wang¹, Yong-Hua Lu¹, Cao-Shui Xiong¹, Yong-Hong Xiong², Tian-Peng Zhao¹, Din-Ping Tsai³, Wei-Chih Lin³

¹ Department of Physics, University of Science and Technology of China, Hefei 230026, P.R. China

² Department of Astronomy and Applied Physics, University of Science and Technology of China, Hefei 230026, P.R. China

³ Department of Physics, National Taiwan University, Taipei, Taiwan, 10617, P.R. China

Abstract: As a promising disk structure for ultrahigh density optical storage, super-resolution near field structure of AgO_x type has been studied by both scanning tunneling microscopy and X-ray diffraction experiments. Irregular surface roughness is observed in super-resolution near field structure. And the decomposition of AgO_x layer at 160 °C is confirmed. Both results of experiments demonstrate that super-resolution near field structure of AgO_x type can satisfy the conditions of exciting surface plasmons.

Key words: Super – resolution near field structures – surface plasmons

1. Introduction

Super-resolution near field structure (Super-RENS) has attracted considerable attentions in recent years as a technology to obtain ultrahigh density storage [1–3]. The most important advantage for Super-RENS is the superior spatial resolution with no diffraction limit. Tominaga et al. have successfully shown that a Super-RENS of polycarbonate/SiN (170 nm)/Sb (15 nm)/SiN (20 nm)/ GeSbTe (15 nm)/SiN (20 nm) on a digital versatile disk (DVD) gives the estimated recorded marks of less than 100 nm at a constant linear velocity of 2.0 m/s [4]. The carrier-to-noise ratio (CNR) can be 25 ~ 40 dB. Most recently, Tominaga demonstrated that AgO_x type Super-RENS with a 15 nm AgO_x layer as the nonlinear optical layer has much stronger near-field intensity and better carrier-to-noise ratio [5]. As to its mechanism, Tsai et al. [4, 6] considered it as localized surface plasmons (SP's) effect and demonstrated that the near field transmission intensity profile is more than calculated profile by 2.25. But, no direct and detailed experiments are reported until now. In

this paper, we make the theoretic analysis how it is possible to excite SP's in the Super-RENS and prove it by corresponding experiments.

2. Theory

Theoretical dispersion of surface plasmons for semi-infinite crystals is given by [7]

$$k(\omega) = \frac{\omega}{c} \left[\frac{\varepsilon_1(\omega)\varepsilon_2}{\varepsilon_1(\omega) + \varepsilon_2} \right]^{1/2} \quad (1)$$

where k is the wave vector parallel to the surface, ε_1 the real part of the dielectric function of the crystal, and ε_2 is the dielectric constant of the adjacent medium. Eq. (1) has a real solution for k at frequency ξ when $\varepsilon_1(\xi) < 0$ and $|\varepsilon_1(\xi)| > \varepsilon_2$ (for air $\varepsilon_2 = 1$). But the application of photons to excite SP meets the difficulty that energy and momentum conservation laws can not be simultaneously satisfied in the frequency range of the dispersion. Ordinarily, in SP experiments [8, 9], attenuated total reflection (ATR) technology is used. However, this method is not fit to explain super-resolution near field structure because of the absence of a prism. Hornauer et al. [10] firstly studied the behavior of the reflection minimum as a function on the roughness of silver and gold surfaces, and proved that the surface roughness is helpful to excite SP on silver and gold surfaces. Under consideration of small roughness case, the roughness profile shall be described by the profile function $z = S(x, y)$, where x, y are the coordinates of a point in the surface and z is measured from $z = 0$, given by a fictitious plane defined as

$$\bar{S} = \bar{z} = \frac{1}{F} \iint_F S(x, y) \, dx \, dy = 0. \quad (2)$$

The assumption of small roughness means that the mean square root

$$(\bar{S^2}) = \delta \quad (3)$$

Received 7 January 2002; accepted 16 July 2002.

Correspondence to: G. Yang

Fax: ++86-551-3601073

E-mail: yguo@mail.ustc.edu.cn

shall be small compared to the wavelength λ of the incident light:

$$\delta \cdot 2 \cos \vartheta \ll \lambda \quad \text{or} \quad \delta \ll \lambda. \quad (4)$$

In the dispersion relation, k has to be replaced by $(k + \Delta k)$ where Δk is a complex quantity: its real part describes the displacement, whereas the imaginary part describes the damping of the plasmon mode on the roughness surface, or

$$\Delta k = \Delta k' + \Delta k'' \quad (5)$$

$$\Delta k' = (\omega/c)^3 \int d^2 k' |s(\Delta k)|^2 A(k, k') \quad (6)$$

$$\Delta k'' = (\omega/c)^3 \int_0^{2\pi} d\phi |s(\Delta k)|^2 B(k, \phi). \quad (7)$$

The term $|s(\Delta k)|^2$ is called “spectral density function” since it gives the spectrum of Δk values which may be transferred from the rough surface to SP's or photons. For the functions of A and B they are given in ref [11].

3. Experiments and discussions

In our experiments, a scanning tunneling microscopy (STM) was used to probe the surface profile of AgO_x layer. The sample is a 15-nm-thick AgO_x layer deposited on quartz glass sandwiched between 170-nm-thick ZnS-SiO₂ and 20-nm-thick ZnS-SiO₂ by magnetron sputtering. The AgO_x layer has a refractive index about $2.8 + 0.01i$, and ZnS-SiO₂ has a refractive index about $2.25 + 0.01i$. Fig. 1 is STM picture of AgO_x at 200 °C, and fig. 2 is the magnified picture of fig. 1. Irregular surface roughness is observed from both figures. This result shows that it is possible to simultaneously satisfy the energy and momentum conservation on exciting SP's in the Super-RENS.

Fig. 3 shows X-ray diffraction patterns of AgO_x layer at different temperature. When increasing tem-

Fig. 1. STM picture of AgO_x at 200 °C.

Fig. 2. The magnified picture of figure 1.

perature, X-ray diffraction was no obviously varied between 20 and 150 °C. But Ag characteristic peak appears near Ag⁺ at 160 °C, and it increases with temperature. It indicates that AgO_x layer decomposes to silver and oxygen at 160 °C and becomes a complicated mixture of Ag and AgO_x. It is known that the real part of the dielectric constant ϵ_{AgO_x} , $\text{Re}(\epsilon_{\text{AgO}_x}) =$

Fig. 3. X-ray diffraction patterns of AgO_x layer at different temperature.

7.8 [6], does not satisfy the inequation $\text{Re}(\epsilon_{\text{AgO}_x}) < 0$, as shown above. But the Ag has a refractive index about $0.07 + 3.65i$ and the real part of the dielectric constant ϵ_{Ag} is negative, i.e. $\text{Re}(\epsilon_{\text{Ag}}) = -13.32$, which satisfies the inequation $\text{Re}(\epsilon_{\text{Ag}}) < -1$. It suggests that Super-RENS can satisfy the theoretical dispersion of SP's.

According to both results of experiments and other results as shown before [6], the principle of Super-RENS can be described as that AgO_x layer decomposes to silver and oxygen during photoactivation or thermoactivation, and at its surface the incident light excites SP's which can not be propagating but evanescent at the local metal-dielectric boundary.

4. Conclusions

In conclusion, we experimentally demonstrate that the theoretic necessary conditions of exciting SP's can be satisfied in Super-RENS. Irregular surface roughness of Ag_xO layer is observed by STM. It can make photons and SP's coupling at Ag_xO layer. In addition, transformation of Ag_xO layer at 160°C is confirmed by X-ray diffraction experiment. AgO_x layer decomposes to silver and oxygen at 160°C and becomes a complicated mixture of Ag and AgO_x . Noble metal Ag is good material for exciting SP's. Both significant experimental results show that surface plasmons effect plays important role in Super-RENS.

The subject is supported by National Research Fund for Fundamental Key Projects No. 973 G19990330.

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