Read-only memory disk with AgO_x super-resolution mask layer

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A novel read-only memory (ROM) disk with an AgO_x mask layer was proposed and studied in this letter. The AgO_x films sputtered on the premastered substrates, with pits depth of 50 nm and pits length of 380 nm, were studied by an atomic force microscopy. The transmittances of these AgO_x films were also measured by a spectrophotometer. Disk measurement was carried out by a dynamic setup with a laser wavelength of 632.8 nm and a lens numerical aperture (NA) of 0.40. The readout resolution limit of this setup was $\lambda/(4NA)$ (400 nm). Results showed that the super-resolution readout happened only when the oxygen flow ratios were at suitable values for these disks. The best super-resolution performance was achieved at the oxygen flow ratio of 0.5 with the smoothest film surface. The super-resolution readout mechanism of these ROM disks was analyzed as well.

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Super-high density optical data storage, which requires the size of recording marks to be smaller than the optical diffraction limit, is very attractive for high definition television system and computer network servers. In 1998, Tominaga *et al.* proposed a super-resolution near-field structure (super-RENS) technique[1] and realized the recording and readout of super-resolution marks with size of $80-100$ nm. The super-RENS technology has progressed from an original Sb mask type[1] to an AgO_x mask type[2,3] and a PtO_x bubble type[4] during the past 6 years, and marks with size of 100 nm with high carrier-to-noise ratio (47 dB) and stability have been achieved for the PtO_x bubble type[4]. Attentions have been focused on the working mechanisms of the AgO_x mask type[2,3,5–8]. In most explanations, Ag particles decomposed from AgO_x during laser irradiation were thought to play an important role in the super-resolution readout.

At the same time, super-resolution read-only memory (ROM) study is very attractive because no recording process is involved, therefore, recording problems can be neglected and only the readout characteristics are extracted. This is the biggest advantage to super-resolution ROM study from the point of view of a basic and fundamental understanding of super-resolution readout phenomena[9]. In 1993, Yasuda *et al.* first introduced the super-resolution technique into ROM by adopting the mask method, they came to realize the super-resolution readout[10]. After that, many kinds of mask materials, such as $Zn_{1-x}Cd_xSe$[11], doped semiconductor glass, organic dyes[12–14], Sb[15], Ge, Si, Mo, W[9], Ti[16], ZnO[17], and PtO_x super-RENS multilayer structure[18] have been used. Although the super resolution effects of AgO_x dependence on the oxygen flow ratios in the super-RENS have been studied by Fuji *et al.*[2,3,19,20], AgO_x used on ROM disk has not been attempted. Moreover, the ROM disk differs from the super-RENS disk. Kikukawa *et al.* found the ROM disk with a single-layered Sb mask layer performed better than that with the super-RENS structure of SiN/Sb/SiN[9]. In this letter, the single-layered AgO_x film as the mask layer used on ROM disks prepared at various oxygen flow ratios was proposed and its super-resolution characteristics and super-resolution readout mechanisms were investigated.

In our experiment, the premastered polycarbonate substrates with pit depth of about 50 nm and pit length (full width at half maximum, FWHM) of 380 nm were fabricated. AgO_x films (with different $O_2/(O_2+Ar)$ ratios) were sputter-deposited on these substrates and K9 glass plates at the background pressure of less than 1.0×10^{-4} Pa. The substrates with these single-layered mask layers were studied by an atom force microscopy (AFM) (AJ-III, AJ Nano Science Co.) to examine the films surface morphology. The spectrum characteristics of these films sputtered on K9 glass plates were also measured by a spectrophotometer (Lamda 900UV/VIS/NIR, Perkin-Elmer Co.). Disk measurement was carried out by a dynamic tester with a laser wavelength of 632.8 nm and a lens numerical aperture (NA) of 0.40. A thin $ZnS\text{-}SiO_2$ protective layer was covered on the mask layer for the dynamic readout test samples. Generally, the resolution limit of the optical readout was given as $\lambda/(4NA)$, therefore, the resolution limit of our setup was about 400 nm, which was larger than the recording pits on the substrates. In the retrieval of the marks (380 nm) on the same premastered ROM disk (with Ag or Al reflective layer), the pits could not be read out.

Figure 1 shows the AFM images of as-deposited AgO_x films with thickness of 30 nm prepared at various oxygen flow ratios ($O_2/(O_2+Ar)$) on the identical premastered substrates. Pits with size of about 380 nm in length could be clearly observed. However, the AgO_x films prepared at different oxygen flow ratios had a very different surface morphology. At the oxygen flow ratio of 0.25 (shown in Fig. 1(a)), silver particles with sizes of about 100 nm were found to be dispersed in the AgO_x matrix. As the oxygen flow ratios increased to 0.5 and 0.7 (shown in Figs. 1(b) and (c), respectively), nano-sized

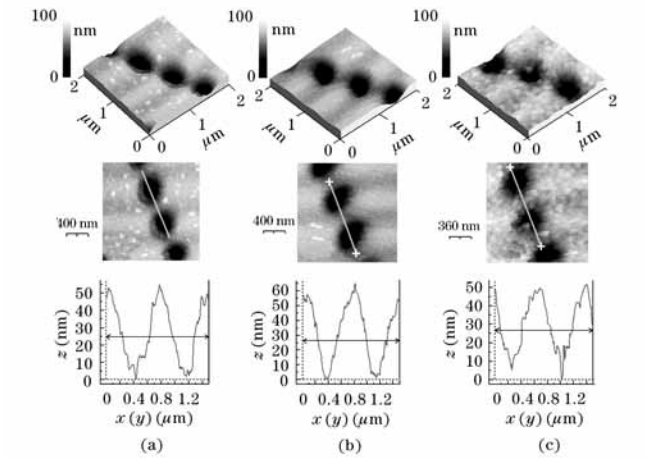

Fig. 1. AFM images of premastered substrates covered with the single-layered AgO_x films prepared at oxygen flow ratios ($O_2/(O_2+Ar)$) of 0.25 (a), 0.5 (b), and 0.7 (c). Pits length shown by the white lines in the middle is about 1500 nm.

silver particles could hardly be found. These results showed that AgO_x films prepared at a low oxygen flow ratio would be composed of metallic silver particles because the oxygen injection rate was not high enough to react with all the sputtered silver atoms. This was consistent with the results reported by Y. Her *et al.*[21]. And at the oxygen flow ratio of 0.5, the film had the smoothest surface quality and the smallest roughness, this might be because the AgO_x was mostly composed of Ag_2O[2]. While at the oxygen flow ratios of 0.25 or 0.7, the AgO_x was composed of Ag and Ag_2O, or Ag_2O and AgO, the mixing of these two components leaded to the larger roughness of the films.

Figure 2 shows the dependence of transmittance of AgO_x films with thickness of 30 nm prepared at various oxygen flow ratios on wavelength. At the oxygen flow ratio of 0.25, AgO_x film exhibited nearly the same spectral characteristics similar to Ag thin film (although not presented here), which indicated AgO_x might be composed of much Ag particles or clusters. This was consistent with the AFM images. The low transmittance at visible light wave band was due to the large extinction coefficient (k) and very small refractive index (n). And a high transmittance apex appeared at ultraviolet light wave band (from 300 to 350 nm) which might be induced by the very small k ($k < 1$) and relative large n ($0.5 < n < 1.5$) to k. At the oxygen flow ratios of 0.5 and 0.7, AgOx films had a high transmittance at visible light wave band because of small k[2].

Figure 3 shows the waveform signals and the corresponding frequency domain signals of dynamic results of ROM disk with the traditional Ag reflective layer and with the AgO_x mask layers prepared at different oxygen flow ratios. The readout power was as high as 4.5 mW with a readout velocity of 2 m/s. It was found that at the oxygen flow ratio of 0.25, the super-resolution effect did not happen as the traditional Ag reflective layer ((shown in Figs. 3(a) and (b)). However, at the oxygen flow ratio of 0.5 (Fig. 3(c)), very strong super-resolution signals could be detected and its carrier-to-noise ratio (CNR) was about 30 dB. At the oxygen flow ratio of 0.7 (Fig. 3(d)), the CNR was about 22 dB.

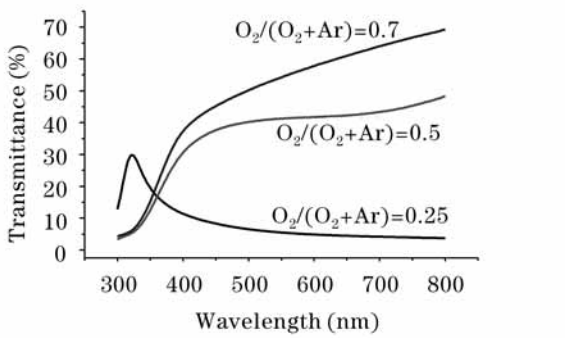

Fig. 2. Wavelength dependence of transmittances of the AgO_x films prepared at various oxygen flow ratios.

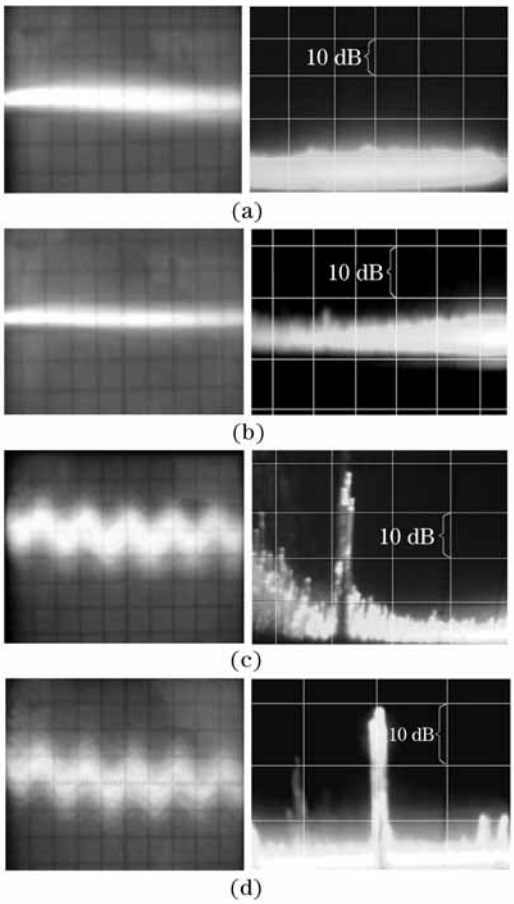

Fig. 3. The waveform signals (left) and the corresponding frequency domain signals (right) of the dynamic results of ROM disk with traditional Ag reflective layer (a), and with the AgO_x mask layers prepared at oxygen flow ratios of 0.25 (b), 0.5 (c), and 0.7 (d).

Figure 4 shows the readout CNR dependence on the readout power of the ROM disks with the AgO_x mask layer with film thickness of 30 nm prepared at various oxygen flow ratios. At the oxygen flow ratio of 0.25, super-resolution readout did not happen at any readout power. This was the same as the conventional disk using Ag or Al as the reflective layer on the same premastered substrates (380 nm) which could prove the readout resolution limit of our system. However, at the oxygen flow ratio of 0.5 and 0.7, very obvious super-resolution readout was achieved and the CNR was a little higher for

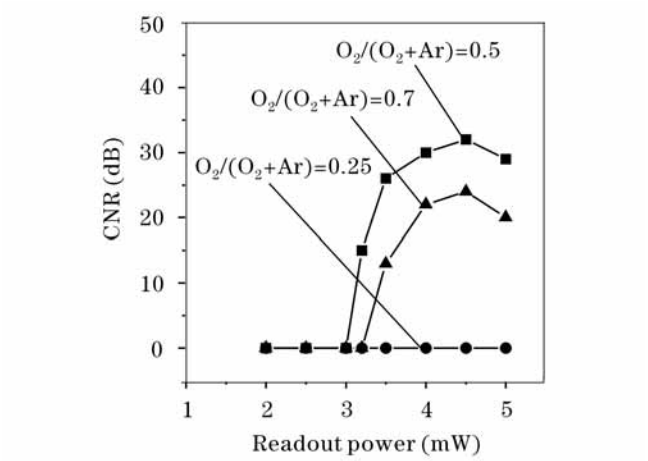

Fig. 4. Readout CNR dependence on the readout power of the AgO_x ROM disks prepared at various oxygen flow ratios. The readout velocity was 2 m/s.

the former. So it indicated that the super resolution effect could only be achieved at suitable O_2 gas ratios for the AgO_x ROM. It was also found that the resolution effect (CNR) had a nonlinear relationship with the readout power. The super-resolution effect appeared only when the readout power was above a certain threshold value which was about 3.5 mW in our experiment, corresponding to about $400-500$ °C in the AgO_x mask layer considering the readout velocity. This temperature was much higher than the decomposing temperature of AgO_x (about 200 °C). As we know, there were two different kinds of microstructures that could be produced in the AgO_x mask layer by different input laser energies[6,22]. At a lower input energy, the centered silver dots could be formed with a high reflectance. While at a higher input energy, an Ag nano-aperture (also called Ag cylinder or ring) tended to be formed with a high transmission. So the very high readout power in our experiment indicated that the super-resolution effect might be closely related to the formation of the Ag nano-aperture.

In fact, the small Ag nano-aperture could significantly reduce the readout laser spot size, which might be the most important factor in the super-resolution readout. And the interaction between Ag particles with the marks in the near-field during laser irradiations could effectively enhance the readout signals [5–8]. At the low oxygen ratio, the film had a low transmittance and a similar spectral characteristic as Ag thin film, the Ag particles or clusters dispersed in the AgO_x film scattered (reflected) nearly all the light back and the Ag nano-aperture which might play the most important role in the super resolution readout could not be formed. So, although it could also enhance the readout signals, but it did not achieve super-resolution effect. At oxygen ratio of 0.7, the Ag particles filled in the nano-aperture might be less than those at the oxygen flow ratio of 0.5[6]. So the readout CNR at oxygen flow ratio of 0.7 was a little lower than that at the oxygen flow ratio of 0.5. This was consistent with the super-resolution and near-field enhancement effects in the super-RENS[6].

A novel ROM disk with an AgO_x mask layer at various oxygen flow ratios was prepared and investigated. The AgO_x films surface were studied by an AFM and their spectral characteristics were also measured by a spectrophotometer. Dynamic results showed that the super-resolution readout could be achieved only at suitable oxygen flow ratios. The best super-resolution readout was obtained at the oxygen flow ratio of 0.5 with the smoothest film surface. The super-resolution readout mechanism was analyzed as well. Our results might be helpful to a better understanding of the readout mechanism in the super-RENS.

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