Enhancement Effect of Patterning Resolution Induced by an Aluminum Thermal Conduction Layer with AgInSbTe as a Laser Thermal Lithography Film *

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We employ an aluminum (Al) film as a thermal conduction layer under the laser thermal lithography AgInSbTe phase-change film to improve the patterning resolution in laser thermal lithography. The patterns were fabricated by laser writing and wet-etching. The laser writing was conducted by a setup where the laser wavelength and the numerical aperture of the converging lens were 405 nm and 0.90, respectively. The wet-etching was carried out in a 17wt% ammonium sulfide solution. Experimental results indicate that the patterning resolution enhancement induced by an Al thermal conduction layer is more than 20% compared with that of the samples without an Al thermal conduction layer. The analysis reveals that the resolution-enhancing effect may be due to the changes of heat diffusion directions induced by the Al thermal conduction layer.

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As a new technology for fabricating patterned structures, laser thermal lithography has attracted substantial attention[1–5] due to its promising applications in high-density optical information storages, micro/nano-electro-mechanical-system devices, light-emitting diodes, and microelectronics.[6–10] In the thermal lithography, when the thermal lithography film was irradiated by a laser beam, the physical and chemical properties of the film change at the center of the laser spot due to the light absorption-induced temperature rise, resulting in a difference of the etching rate between the irradiated and non-irradiated regions. The micro/nanostructure can then be uncovered by wet-etching. Several thermal lithography materials, including phase-change films (e.g., Ge-Sb-Te, ZnS-SiO_2 or Ge-Sb-Sn-O) and metal oxide films (e.g., W-O), have been developed.[1,5,11–13] In applications of the laser thermal lithography, one of the most important issues is the improvement of the lithographic resolution and decrease of the characteristic size of patterns. Several methods have been used to reduce the patterning size, such as reducing the laser wavelength, increasing the numerical aperture (NA) of the converging lens, and controlling the threshold temperature of the laser thermal lithography effect.[4,14] The use of a metal film with high thermal diffusion coefficient as the thermal conduction layer to reduce the characteristic size has not yet been reported. In this Letter, an aluminum (Al) film was used as a thermal conduction layer under the laser thermal lithography AgInSbTe phase-change film to enhance the lithographic resolution. The patterns were fabricated by direct laser writing, and then wet-etching by ammonium sulfide solution. The lithographic resolution of AgInSbTe patterning was enhanced by more than 20% compared with the samples without an Al thermal conduction layer. The method is not only effective, but simpler and of lower cost than other methods; the mechanism of the resolution-enhancing effect is analyzed and discussed as well.

Two kinds of sample structures shown in Fig. 1 were designed. Figure 1(a) gives the sample structure of AgInSbTe (100 nm)/Al (100 nm)/glass substrate, where the Al film was used as a thermal conduction layer under the laser thermal lithography AgInSbTe phase change film. The Al film was deposited on a glass substrate by the direct current magnetron sputtering method, and the AgInSbTe film was deposited on the Al film by rf magnetron sputtering. The background vacuum was about 2×10^{-4} Pa, the working pressure was 0.8 Pa, and the working gas of argon was at 80 sccm. In order to analyze the enhancing effect of the Al layer, another sample without the Al layer, AgInSbTe (100 nm)/glass substrate, as shown in Fig. 1(b), was used for comparison.

The AgInSbTe patterns were fabricated by direct laser writing and subsequent wet-etching. The laser writing was conducted by the setup whose laser wavelength λ and NA were 405 nm and 0.90, respectively. In the experiment, the laser power was tunable in the range from 2 mW to 7 mW. The wet-etching was carried out in analytical-reagent grade 17wt% ammonium sulfide solution from Sinopharm Chemical Reagent Co., Ld. The characteristic size of patterns was mea-

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sured by an atomic force microscope (AFM, Veeco, Multimode V).

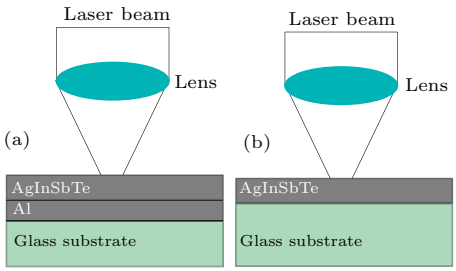


Fig. 1. The schematic diagram of the sample structures: (a) AgInSbTe/Al/glass substrate, and (b) AgInSbTe/glass substrate.

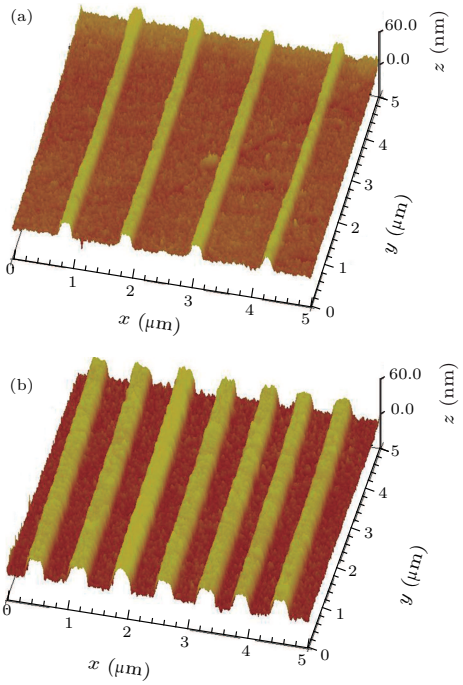


Fig. 2. AFM images of pattern fabricated by laser thermal lithography ($\lambda = 405$ nm, NA = 0.9, laser power = 3 mW, etchant: 17wt% $(NH4)_2S$) (a) on the AgInSbTe/Al/glass substrate sample and (b) on the AgInSbTe/glass substrate sample.

Figure 2 gives the experimental results of the patterns. Figure 2(a) shows the AFM images of the fabricated pattern on the AgInSbTe/Al/glass substrate sample, and the pattern from the AgInSbTe/glass substrate sample is presented in Fig. 2(b). As aforementioned, the first step of fabrication was the laser writing, and the laser writing power was 3 mW. The second step was the pattern etching in 17wt% ammonium sulfide solution. A uniform line pattern on both the samples were observed, and the line-width on the AgInSbTe/Al/glass substrate sample was 288 nm. This line width was smaller than that on the AgInSbTe/glass substrate sample, where the line width was about 363 nm. That is, the resolution of the patterns on the sample with an Al thermal conduction layer was enhanced to as high as 20.7% compared with that on the sample without an Al thermal conduction layer. By changing the writing laser power from 2 mW to 7 mW, the enhancement effect by the Al thermal conduction layer remained at about 20%. Table 1 depicts the experimental results. One can also find from Table 1 that the characteristic size of 176 nm line width was obtained at 2 mW writing power, and this characteristic size is smaller than one half of the laser writing wavelength.

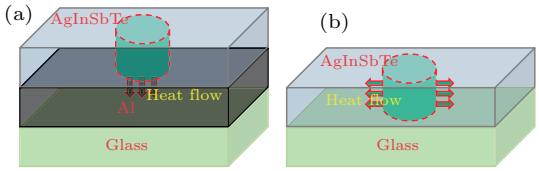


Fig. 3. The schematic diagram of the thermal diffusion direction in (a) the AgInSbTe/Al/glass substrate sample and (b) AgInSbTe/glass substrate sample.

To understand the mechanism of resolution enhancement, the heat diffusion in the two kinds of samples was analyzed. Generally speaking, when a Gaussian laser beam is focused on the lithography film, the absorbed light energy is partially transformed into heat. For the AgInSbTe/glass substrate sample, when the writing power was higher than 5 mW, the line width (shown in Table 1) was larger than the laser spot size of 550 nm, which could be calculated by $1.22\lambda/\mathrm{NA}$. Setting that the thermal diffusivities of the AgInSbTe and Al were σ_l and σ_ν, respectively, according to Ref. [15], the heat flow through the AgInSbTe and Al could be estimated to be $Q_l \sim \sigma_l \pi d t$ and $Q_v \sim \sigma_\nu \pi d^2/4$, respectively. To determine the dominant direction of the heat flow, a heat propagation parameter η is defined as

$$\eta = \frac{Q_l}{Q_v} = \frac{4\sigma_l t}{\sigma_\nu d}, \tag{1}$$

where Q is the heat flow, t was the film thickness of the AgInSbTe layer, and d is the laser spot size. For the AgInSbTe/glass substrate sample, the thermal diffusivities of AgInSbTe and glass substrate are 1.85 and 0.75 mm^2/s, respectively.[16,17] The heat propagation parameter is $\eta = 1.8 > 1$. For the AgInSbTe/Al/glass substrate sample, the thermal diffusivity of the Al film is 89 mm^2/s,[17] and the heat propagation parameter is $\eta = 0.015 \ll 1$. The thermal diffusion direction within the AgInSbTe layer of the AgInSbTe/glass substrate sample is mainly transverse, which is schematically shown in Fig. 3(a). However, for the AgInSbTe/Al/glass substrate sample, the dominant heat flow is toward the Al film, as shown in Fig. 3(b). Thus, the heat diffusion direction in the AgInSbTe/Al/glass substrate sample is mainly vertical. That is, the heat flow direction changes from transverse to vertical diffusion due to the Al thermal conduction layer. Conse-

quently, the temperature profile narrows to the point of surpassing the phase change threshold of the AgInSbTe film in the AgInSbTe/Al/glass substrate sample, thus a higher patterning resolution can obtained.

Table 1. The comparison of line-width of patterns.

Laser power (mW)	Patterning width (nm)		Resolution enhancement ratio
	AgInSbTe/glass	AgInSbTe/Al/glass	
2	227	176	22.5%
3	363	288	20.7%
4	442	350	20.8%
5	537	422	21.4%
6	647	500	22.7%
7	750	590	21.3%

In summary, the use of an Al thermal conduction layer inserted between the AgInSbTe film and glass substrate to enhance the AgInSbTe patterning resolution is developed. The AgInSbTe patterns were fabricated by laser writing and wet-etching. Ammonium sulfide solution was used as the etchant. The patterning resolution on the sample with an Al thermal conduction layer under the AgInSbTe thin film was enhanced by more than 20% compared with the sample without an Al thermal conduction layer. When the laser power was 2 mW, the pattern with a linewidth of 176 nm was obtained and this size was less than one half of the laser wavelength. The analysis reveals that the resolution enhancing effect may arise from the changes of heat diffusion direction induced by the Al thermal conduction layer. This patterning resolution enhancement method of using Al film as a thermal conduction layer is simple and efficient, and can be applied in the fields of micro/nano-structure manufacture.

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