Exploiting optical near-fields for phase switching and nanopatterning

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ABSTRACT

We report a novel technique for exploiting optical near-fields of dielectric micro- and nanospheres upon illumination with short laser pulses for phase switching in $Ge_2Sb_2Te_5$ films. The complex intensity distribution of the optical near-field at the crystalline film surface is imprinted and leaves behind a characteristic amorphous fingerprint, which can be read out with optical microscopy, AFM and field emission SEM. We achieve full control over the resulting patterns by playing with the illumination conditions (laser wavelength, angle of incidence, polarization) and the size and arrangement of the particles. The experimental results are well described by a model based on Mie scattering theory solving Maxwell's equations. We demonstrate that a written pattern can be erased also by near-fields and that erased patterns can be recovered by adjusting the light intensity. The influence of pulse duration and light wavelength on the minimum recordable features size and surface roughness of the pattern is explored. Minimum features with sizes well below 200 nm can be written, which are down scaleable by reducing pulse duration and wavelength.

Key words: optical near-field, phase switching, nanopatterning, nanoparticles, data storage.

1. INTRODUCTION

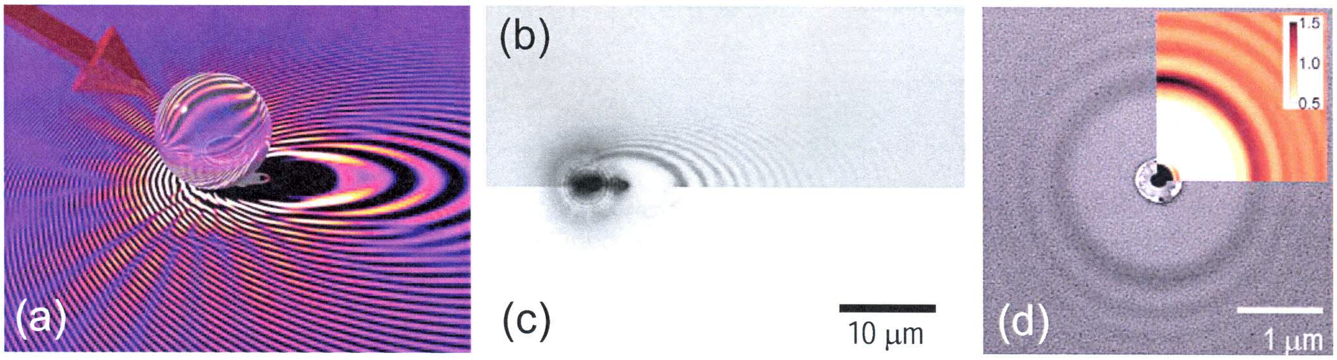
Light interacting with small particles gives rise to a complex 3-dimensional (3-D) optical near-field (ONF) surrounding the objects. ONFs are already being exploited for microscopy[1] and material processing[2] at the submicron scale. ONFs depend on the properties of the light (wavelength and polarization), the angle of incidence, the properties of the particle (dielectric constant and diameter) and the optical properties of the supporting substrate. While, in principle, ONFs can be tailored by adjusting the above mentioned parameters to produce a desired intensity distribution at the surface of the substrate supporting the particle, in practice this requires a detailed study of the influence of each parameter on the ONF. Different models have been proposed to calculate the ONF distribution and the current experimental technique of choice is near-field ablation accompanied by AFM measurements. However, to date the agreement between experiment and model is far from being perfect. We have recently introduced a new method to visualize the complex ONF distribution by imprinting it directly on a crystalline $Ge_2Sb_2Te_5$ (GST) film and forming an amorphous pattern, employing infrared fs laser pulses.[3] We have also demonstrated the possibility of visualizing ONFs using ultraviolet nanosecond laser pulses,[4] which underlines the applicability of this technique to a broad range of laser wavelengths and pulse durations. In the present work we focus on controlled writing and erasing operations of complex patterns in phase change materials employing near-fields, as well as on recovery of erased patterns and writing of small amorphous nanobits.

2. EXPERIMENTS

Samples consisted of sputter-deposited 40-nm-thick, fcc GST films on Si wafers covered by a 10-nm-thick SiO_2 layer. Different sizes of spherical silica particles ($\varnothing$ = 4.7 μm, 1.6 μm, and 0.4 μm) were deposited on these films under conditions that ensure particle isolation. The laser sources used for performing experiments allowed for irradiation at different wavelengths (800 nm, 400 nm, 193 nm) and different pulse durations (20 ns, 8 ns, 350 ps and 120 fs). The loosely focused laser beam was incident on the sample at a user-selected angle, polarization and peak energy. After irradiation, the patterns were imaged using optical microscopy, AFM and field emission SEM. The model we developed calculates the electric field distribution by rigorous solution of Maxwell's equations using Mie scattering theory and taking into account the substrate, directly yielding the fraction of light that penetrates into the film and is absorbed by it.

3. RESULTS & DISCUSSION

Figure (a) shows the scheme of nanoscale patterning exploiting optical near-fields of dielectric microspheres (from Ref. 3). The arrow indicates the direction of the incident light pulse. (b) displays the upper part of an optical image of an amorphous near-field pattern written in GST with the ONF of a 4.7 μm sphere at 193 nm and 53° angle of incidence. For comparison, (c) shows the corresponding lower part of the same region as in (b) after pattern erasure using lower light intensity. (d) shows a SEM image of a pattern written with the ONF of a 1.6 μm sphere at 193 nm and normal incidence, in comparison with the calculated intensity distribution (inset).



4. CONCLUSION

Optical near-fields can be imaged precisely using chalcogenide thin films as recording media. The imprinted complex patterns are well described by our model and can be adjusted at wish by selecting the illumination conditions. Written patterns can be erased by near-fields, erased patterns can be recovered, and minimum features with sizes well below 200 nm are obtained, paving the way for applications in erasable data storage, including data encryption and multiplexing.

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