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