Phase change materials and superrens

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INTRODUCTION

In a never ending quest for a higher data storage capacity, several different solutions are evaluated. As a straightforward conceptual evolution of CD, DVD and BD, it should be proposed to reduce the wavelength and to increase the numerical aperture. The wavelength reduction is limited to a small amount compared to the BD wavelength (405 nm) since deep UV laser diodes are still at the research level. To increase a numerical aperture of 0.85 (BD) at a significantly higher level implies the use of near-field optics. Optical near field generation can be obtained by several means: metallic coated cone shaped fibers, metallic diffusing tips, VCSEL with holes, Solid Immersion Lens, …. All those techniques require to control very precisely the distance between the near field source and the recording area. Despite impressive progress on servo, regarding SIL for example, this requirement might compromise the removability and/or the handling of the optical disc. Those two points are key properties of optical discs since manufacturer are targeting content distribution and personal archiving.

Hence superresolution [1,2,3,4] appears to be an appealing solution since the near field is generated inside the disc thin film stack and the distance between the source and the recording area is fixed by a constant physical layer thickness. Huge progresses have been made recently on recordable superrens disc, however some progresses have still to be made on ROM disc and the physical understanding of the materials behaviour still seems open to discussion. It is our objective here to propose an analysis of superrens based on optical and electronic properties of phase change materials and to see how this analysis has allowed us to find new structures of superrens discs.

PHENOMENOLOGICAL ANALYSIS

When a photon is incident on a semiconductor material it can excite an electron from the valence band to the conduction band if the energy of the photon is higher than the gap of the semiconductor material. Those free electrons are generated with a rate G (in s^{-1}). They can come back to the valence band either by collision with the lattice, inducing an increase of the material temperature, or by emission of another photon. This recombination rate (in s^{-1}) is named R. If G is much higher than R, the conduction band has always a certain number of free excited electrons. In this case the optical properties of the material are changed from a semiconducting behaviour to a more metallic one. Then the superrens effect is no more obtained by making a small aperture in the mask layer but by creating a brighter region smaller than the beam size in this layer.

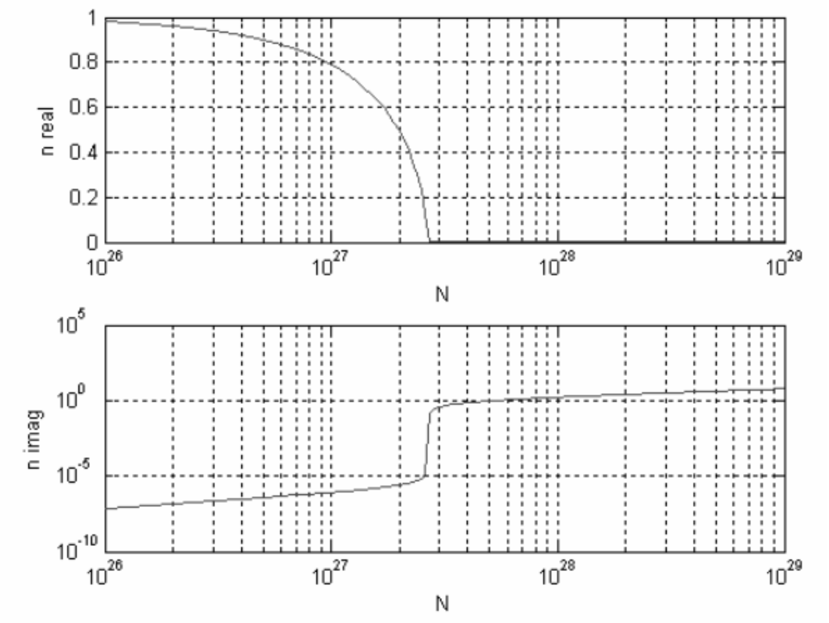
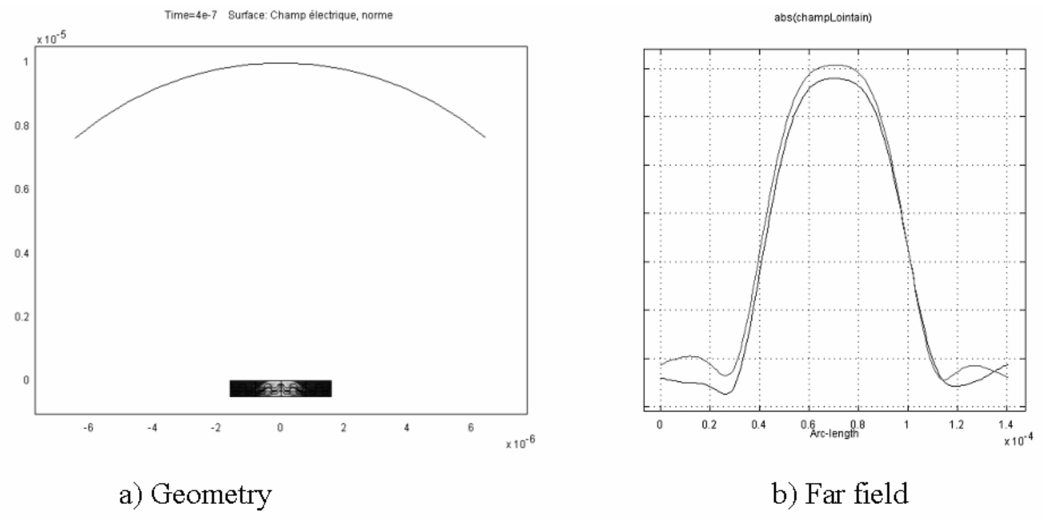


Figure 1: shows the Drude variation of the refractive index (real and imaginary parts) as a function of the free carriers concentration. We point out the drastic change of the imaginary part of the index close to $3.10^{27}e/m^3$.

The complex refractive index is changed in a localized area under the focused laser beam, depending on the number of free carriers (Figure 1). The drastic variation of the indexes (n+i.k) close to $3.10^{27}e/m^3$ is related to a resonating plasma effect. According to the nature and the microstructure of the thin superrens layer, the free carriers can diffuse in the materials and enlarge the photoexcited area. In all cases, this photoexcitation of free carriers can be seen as a mean to modify locally the optical response of the stack and to increase subsequently the resolution. In order to model the optical effect of those free electrons we consider a Drude contribution to the optical properties of the material. This contribution depends on the laser beam power.

We use Comsol software in order to make a multiphysics simulation of the readout process of the superrens disc. Our simulation takes into account the propagation of the electromagnetic field in the stack, the generation of the free carriers, the diffusion of those carriers and their recombination. The simulations are made in two dimensions and the exact structure of the disc is taken into account in the model. The only parameters that have been adjusted are the two previously mentioned ones (G,R) that we choose so that the free carriers concentration reaches a suitable value during the photo-induced process. The complete parameters of the simulation are not mentioned here because we prefer to give an overview of the mechanism without going into not useful details (linear speed 4 m/s,…).

Finally, the electromagnetic field computed in the stack is propagated to a far field plane (or arc, figure2a) where a representative value of the readout signal can be computed through a Sommerfeld integral. The temporal evolution of the signal is calculated through a periodisation of the elementary structure.



a) Geometry b) Far field

Figure 2 a): shows the geometry of the model including both the irradiated domain and the (detector) collecting boundary in arc shape. b): shows the modulus of the electromagnetic far field computed on an arc domain, +/-45°, related to the collecting pupil when the spot is on a pit (lower curve) and between two pits (upper curve).

We notice that the collected flux in the aperture, related to the far electromagnetic field (figure 2b) is lower when the spot is on a pit (blue lower curve) than when it is between two pits (green upper curve).

Our simulations allow us to vary the readout power and then to see if the free carrier generation effect might be an explanation of the superrens effect. Figure 3 represents a simulation of the (normalised) readout signal when scanning a sample with a continuously increasing reading power. The variation speed of the power is considered as much slower than the scanning one. X axis is indexed from 0 to 15mW. The insert exhibits the resolution of the pits at the optimized power. It appears clearly that an increase of the readout power allows to resolve the pits. The phenomenon will be described with a better insight in the following…

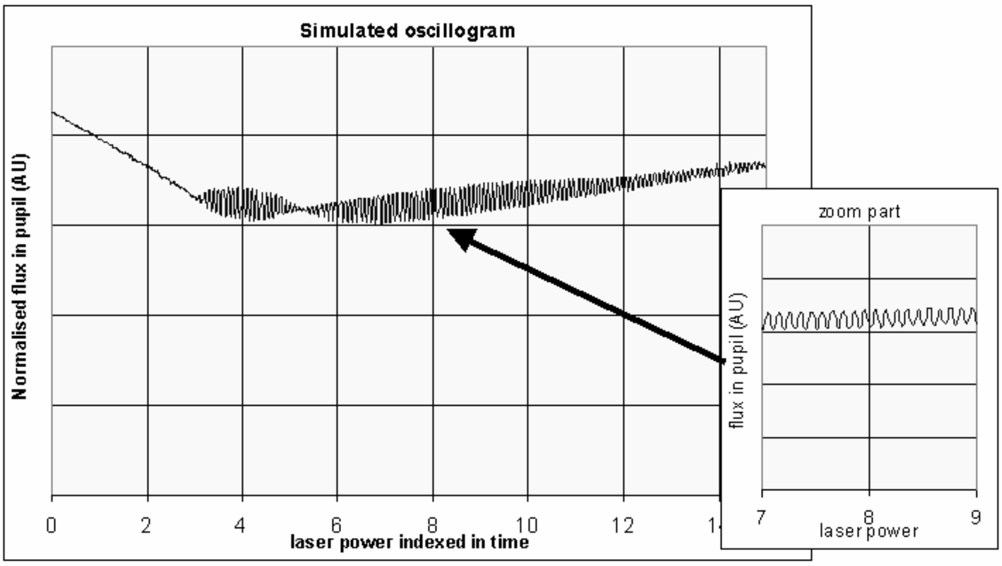


Figure3: represents a simulation of the (normalised) readout signal when scanning a sample with a continuously increasing reading power. The variation speed of the power is considered as much slower than the scanning one. X axis is indexed from 0 to 15mW. The insert exhibits the resolution of the pits at the optimized power.

Figure 4 shows the electromagnetic field and the free carrier density in the stack when the laser beam is focused on a pit or between two pits. A surprising effect is that the intensity of the electromagnetic field and consequently the number of free carriers generated by the laser beam is higher on pit than between two pits.

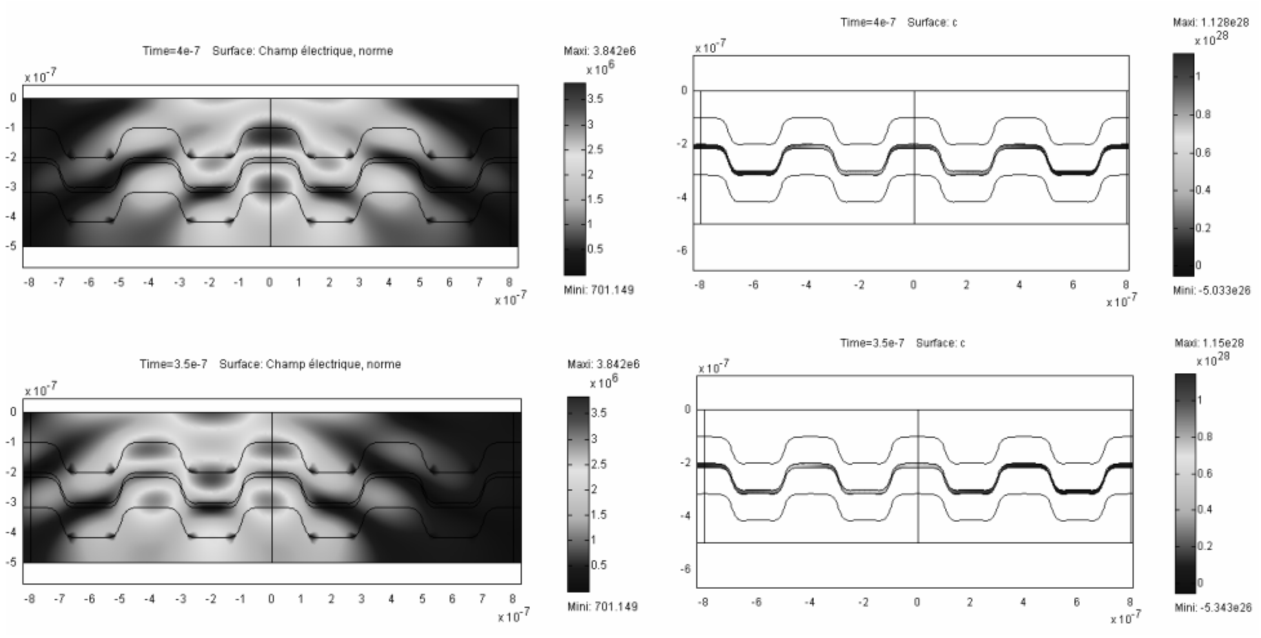
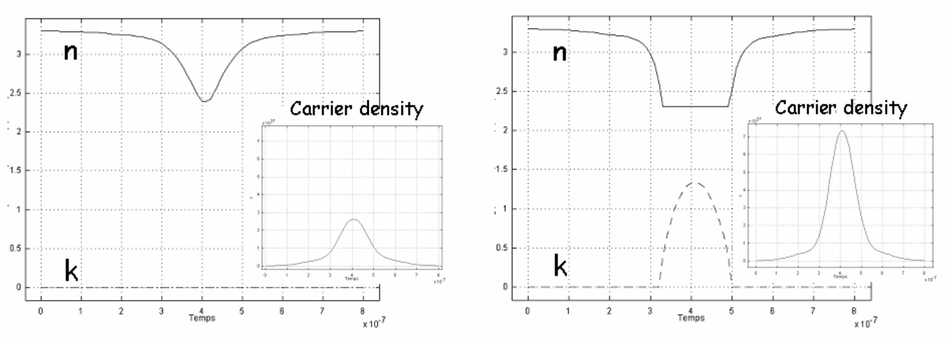


Figure 4: Left images show the structure and the electromagnetic field on pit (upper image) and between two pits (lower image). Right images show free carriers density in both cases (on pit and " in land") – at optimal power. Notice that the brightness of the electromagnetic field is lower in the" in land case", that is in agreement with a lower free carrier density.

If we look at now the evolution of the local optical properties of the material we can see that at low power (figure 5a) the refractive index begins to vary but this variation is not sufficient to induce a superrens effect (variation of the real part of the refractive index only). If we further increase the readout power (figure 5b), the imaginary part of the refractive index then increases on a localized area and allows the superrens effect (as it can be seen on figure 3).



(a) Low power

(b) Optimal power

Figure 5 :(a) and (b) images show the temporal evolution of the indexes (n+i.k respectively solid line and dash line - free carrier contribution only-) recorded on the top of a pit and insert images show the corresponding temporal concentration distribution of the free carriers density. Both cases are presented: (a) at low readout power and (b) at optimal power.

On the basis of this analysis a superrens material was chosen. The experimental results are given below.

EXPERIMENTAL RESULTS

A superrens ROM disc was made on the basis of our analysis. The stack is made of three layers: dielectric / superrens layer / dielectric. Despite the above simulations were made with a DVD format, the experiments were conducted with a Blu-Ray format. The substrate was made by electron beam mastering [5]. Different pit sizes were realized : 80 nm, 100 nm and 160 nm. The pit period is twice the pit size. The track pitch is set to 320 nm in order to simplify the data analysis.

Figure 6 shows the results obtained on a Thomson tester on a substrate with our superrens stack for different mark lengths.

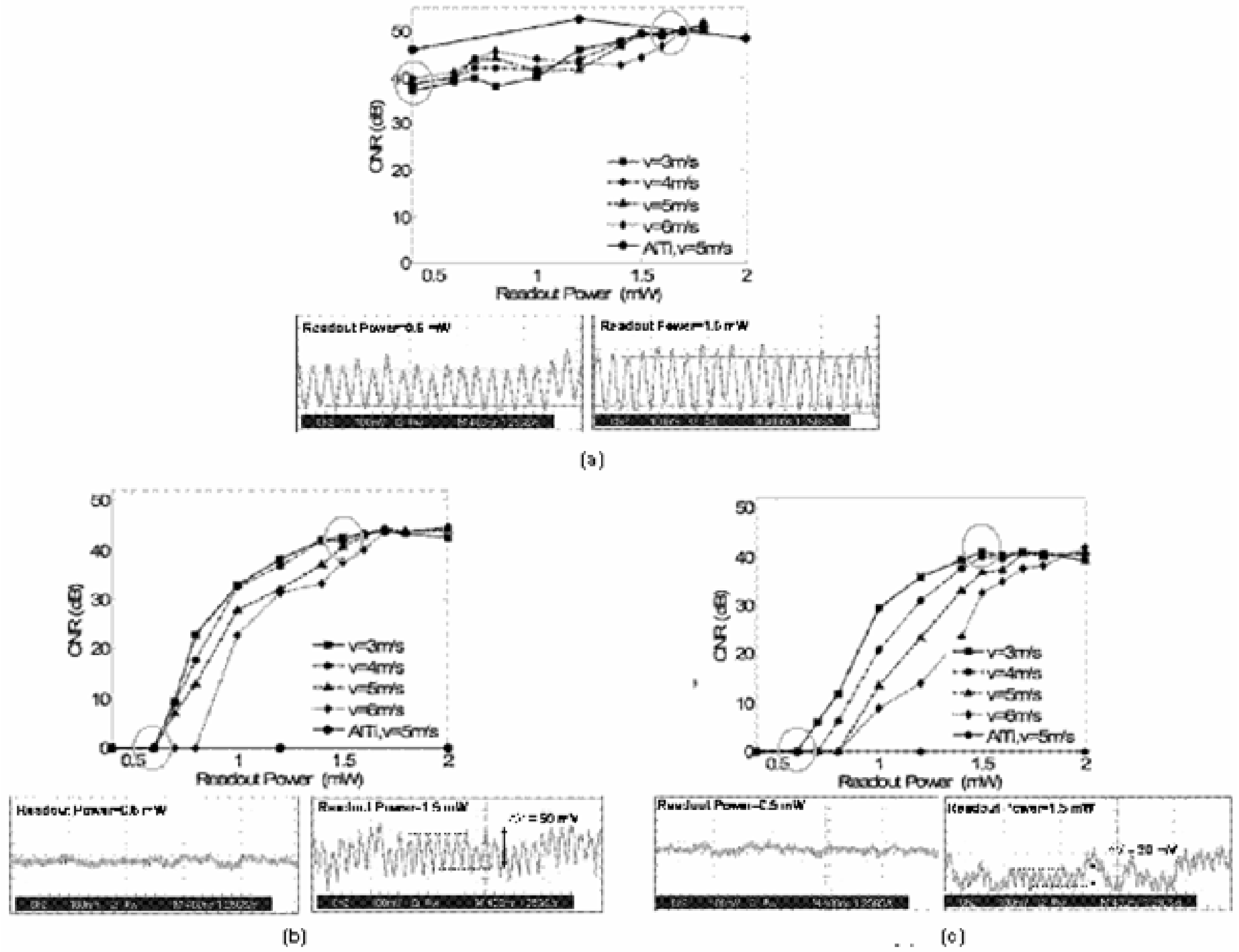


Figure 6 : evolution of the CNR (and corresponding oscilloscope signals) versus readout power for different mark lengths : 160 (a), 100 (b) and 80 nm (c). A sample coated with an aluminium layer is given as a reference of a sample without any superrens effect. The linear speed of the sample is varied from 3 to 6 m/s.

While no signal can be detected with a simple aluminium layer, the different curves show clearly that a 40 dB CNR can be obtained on the 80 nm marks lengths and 42 dB on the 100 nm marks lengths at the optimal power. No CNR can be obtained with the same mark lengths with a reference sample with a simple aluminium layer to reflect light. Classically, the 160 nm marks lengths are well resolved even with an aluminum layer.

The same kind of results can be obtained with a DVD stack. We have also used this new material in a 7 layer structure with PtOx to make a recordable superrens disc. In our lab, superrens structures made with a GeSbTe or AgInSbTe superrens layer show less promising results. This difference is expected with our simulation also.

In all cases the storage density can be increased by a factor of 2 in the tangential direction compared to the base format.

CONCLUSIONS

In this work we have shown a superrens stack for ROM disc and applied the same kind of structure to R disc with PtOx recording layer [6,7] (the same kind of stack can be used for blue and red wavelength). Our model to illustrate the superrens effect in the case of our material is quite simple and seems to fit with experimental results. On one hand, this model will be improved to investigate both the optimised geometry of pits and the stack design (choice of layers thicknesses). On the other hand, we expect to use it to analyse the influence of fluctuations (pattern, flux, indexes,…) in noise generation...

However, it is clear that due to the relaxation of free carriers by collision with the lattice the temperature of the sample might also increase. This modification of the temperature probably changes the optical properties of the superrens layer. In our case we have checked that the variation of the optical properties with temperature given in the literature cannot explain alone the observed phenomenon. However, it is in our objective in a near future to include thermal simulation to the model. We then intend to optimise the substrate geometry, the sample design and the materials (nature and/or microstructure) in order to increase the performances of our discs. The reduction of noise is one of our main targets.

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