Photonic IC for optical detection with sub wavelength resolution

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To increase the information density on optical disks, the pit size should be decreased. In this paper we present theoretical results on how features smaller than the wavelength of the used light can be distinguished. Through a multimodal waveguide, light is focussed on the disk using a combination of the different modes. The light reflects on the disk and couples back into the modes of the waveguide. By using a photonic IC we can detect the variation of this mode to mode coupling, when the bit pattern is moved. From these variations, the bit information on the disk can be deduced.

Introduction

Optical data storage tries to cope with the strong need for exchangeable super high-density, high-data rate storage memories that can be easily copied and can be produced at low cost. In this search for higher information density, the classical diffraction limit forms an important barrier. Near field and solid immersion systems[1] have already passed this barrier, but are not compatible with the exchangeability aspect. In this paper we propose a method to improve the resolution without making the spot size on the disk smaller than the wavelength. The idea is to reconstruct the complete field profile (including amplitude and phase) of the far-field response of light reflecting on the disk. Other research groups have already showed that using interferometry this amplitude and phase information can be measured simultaneously and small features on the sample can be resolved[2].

Our approach is to detect the complete far field by a multimodal waveguide that is moved along the tracks of bit patterns on the disk. In contrast to the free space interferometry approach this component can easily be integrated in a pick-up head. Fig.1 shows a schematic version of our scanning waveguide approach. Through the multimodal waveguide light is focused on the disk, using one of the modes of the waveguide or a linear combination of the modes. This light reflects on the disk and couples back into the different modes of the waveguide. To control those different modes in the waveguide we use a photonic IC, which excites and detects the different order modes in the multimodal waveguide from and to monomodal input and output waveguides. This way we can measure the reflection matrix formed by the mode to mode coupling from the waveguide to the disk and back. Each cell of this matrix gives the fraction that is reflected from light sent through mode i and coupled back into mode j. If we can detect this matrix while the waveguide is moving along the tracks of bumps and holes on the disk, we get a response curve for each of the cells.

There are two approaches to move the waveguide above disk:

- Fig. 2a shows the intermediate field approach. The waveguide is set into a slider that is moved a few microns above the disk. As this already a few wavelengths wide, the evanescent waves are not present any more, as in is the case in the near field. In this approach the same waveguide is used for focussing light onto the disk as for detecting the reflected light.

- Fig. 2b shows the far field approach where a lens system is used to focus the light between the waveguide and the disk. In this approach a beam splitter can be introduced. This way two different waveguides can be used for focussing light on the disk and detecting the reflected light.

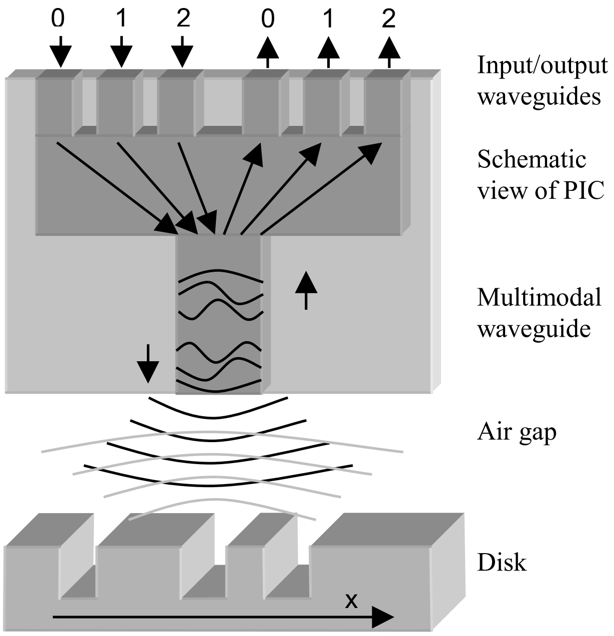

Figure 1: Waveguide-based phase profile discriminator

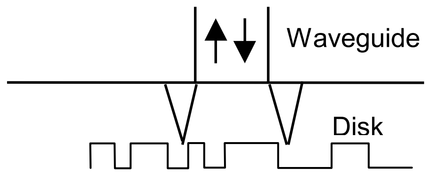

Figure 2a: Intermediate field approach

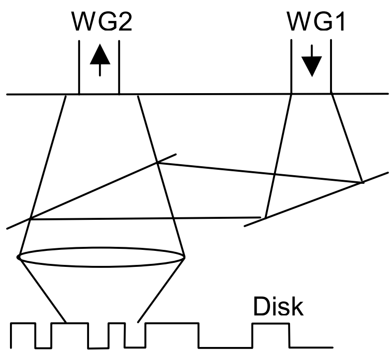

Figure 2b: Far field approach with beam splitter

The aim is that for each different bit pattern of bumps and holes on the disk we get a significantly different group of response curves. If this is the case, the original bit patterns can be deduced from the measured response curves. When however two different bit patterns generate similar response curves, noise in the system will be bigger than the distance between the response curves and it will be impossible to resolve the original bit pattern.

The component above can of course only be used to enhance the resolution in the direction along the tracks. If we would use a waveguide that is multimodal in both directions it may also be possible to decrease the spacing between the tracks themselves.

Simulations and results

The simulations can be divided into two problems:

- The mode-to-mode coupling matrix as a function of the bit pattern on the disk
- Splitting of the different modes to monomodal waveguides for detection

Changes in mode-to-mode coupling matrix as a function of bit patterns

To calculate the propagation of the electromagnetic field in the space between the waveguide and the disk we used the simulation tool CAMFR, a 2D mode solver made at

INTEC. With this simulation tool both the intermediate and the far field approach can be simulated, but we need to use 2D models of waveguide and disk.

At the waveguide-air interface parasitical reflections should be minimized. For the bare waveguide, half of the power of the zero order mode is reflected because of the large refractive index difference of the waveguide and air. For first and second order modes this reflection is even higher. In the case of the far field approach these reflections will deteriorate the signal coming from the disk. It is possible to make a simple AR-coating to drastically decrease the reflections. There is however no simple AR-coating that will do the job for all order modes. Moreover this AR-coating takes some space and the distance between waveguide and disk will be increased. In the simulations below there has been made a trade off for the AR-coating and chosen to minimize the reflection at the interface of zeroth order mode back into zeroth order.

On fig. 3a in dark line is shown how the mode-to-mode coupling is changing when the waveguide is moved along a track. At the top of fig. 3a the bit pattern is shown as a change in reflectivity of the disk. In dash line the response curves of a slightly different bit pattern are shown. However there is no obvious connection between the bit patterns and the response curves, it must be clear that the two different bit patterns generate response curves that are significantly different. On fig. 3b the same curves are shown for the far field approach. The reason that we get similar results is that with the air gap of a few wavelengths the evanescent waves already disappeared and have no influence any more on the intermediate field.

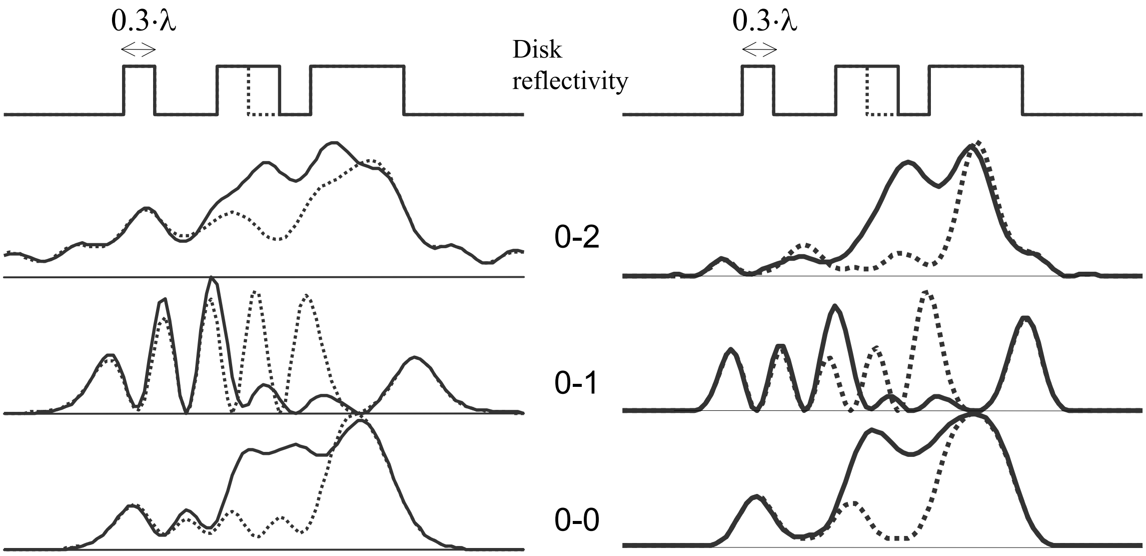

Figure 3a: Bit pattern and mode-to-mode coupling curves in the intermediate field approach

Figure 3b: Bit pattern and mode-to-mode coupling curves in the far field approach

If we measure bit patterns with a smaller spacing, the distance between response curves of different bit patterns tend to decrease drastically. When the distances between the response curves become to small, noise in the system including the crosstalk between the different modes in the photonic IC will make it impossible to resolve the original bit patterns.

Photonic IC for splitting up the modes

To detect the evolution of the mode-to-mode coupling matrix we need a photonic IC. It is hard to detect all elements of this matrix, but it may be sufficient only to detect some of them. It is also evident that it is harder to design a photonic IC for the intermediate field approach, because one single photonic IC is needed for focussing light onto the disk and detecting the reflected light. As mentioned above a low crosstalk for the splitting of the different modes is very important. The component that already splits of zeroth and first order mode is shown on fig 4. It is based on the principle of restricted interference in a multimode interferometer[2][5]. The zeroth order mode from the input is replicated in the central output waveguide. The first order mode at the input is split into two peripheral waveguides. With this component both input modes can be detected separately at the outputs.

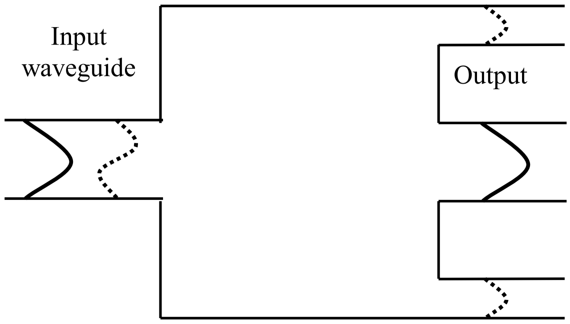

Figure 4: Mapping characteristics of the MMI for zero and first order input mode

Conclusions

The scanning waveguide method shows that two different bit patterns give significantly different response curves at the detectors. Simulations in the intermediate and in the far field show promising results for features spaced by $0.3 \cdot \lambda$. Of course 3D simulations with more accurate disk models should provide a more accurate limit for the feature spacing.

Acknowledgments

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References

[1] T. D. Milster, “Near-field optics: a new tool for data storage”, Proceedings of the IEEE, vol. 88, No 9, pp. 1480-1490, September 2000.

[2] http://www-optics.unine.ch/research/microoptics/high_res_microscope/high_res_microscope.html

[3] http://camfr.sourceforge.net

[4] L.B. Soldano, E.C.M. Pennings, "Optical multi-mode interference devices based on self-imaging: principles and applications", IEEE Journal of Lightwave Technology, vol. 13, pp. 615-627, April 1995.

[5] J. Leuthold, R. Hess, J. Eckner, P.A. Besse and H. Melchior, "Spatial mode filters realized with multimode interference couplers", Optics Letters, vol. 21, pp. 836-838, 1996.