Parallel recording with optical waveguide array

Haifeng Wang[*a], F.H. Groen[b], S.F. Pereira[b], J.J.M. Braat[b]
[a]Department of Physics and Astronomy, Free University Amsterdam,
De Boelelaan 1081, 1081HV, Amsterdam, The Netherlands
[b]Optics Research Group, Faculty of Applied Sciences, Delft University of Technology
Lorentzweg 1, 2628 CJ Delft, The Netherlands

ABSTRACT

We present an analysis of the reading capability of a novel optical pickup consisting of a single-mode and a multi-mode rectangular waveguide. According to the simulations, if one has prior information about the structure of the disk, super-resolution readout could be achieved. The proposed system has the advantage to be compact and should be straightforward to be extended to arrays. The working distance of this optical pickup can be adapted from near- to far-field by changing the length of the multi-mode waveguide.

Keywords: waveguide array, parallel optical pickup, optical recording, data transfer rate, super-resolution reading

1. INTRODUCTION

In order to increase the data transfer rate, different approaches have been proposed such as: focusing the beam from a linear array of laser diodes onto different tracks operated in the far-field[1-5], and using a linear array of sub-wavelength apertures operated in the near field[6-9]. Recently, it was proposed the use optical waveguide to achieve reading in the intermediate field[10-14], and the use of multimode rectangular multi-mode waveguide as an imaging system[13,14]. Considering the latter system, we analyze its reading capability and how it could be used for optical recording purposes, and according to the simulations, very high resolution can be achieved. Apart from being compact and integrable with illumination and detector units, this kind of optical pickup can be extended to linear array, so that all these advantages together makes a nice alternative for optical recording

2. PRINCIPLE

The focusing system is based on the principle of self-imaging and uses a single mode connected to a multimode waveguide. The light propagates inside the multimode waveguide and after a given propagation distance, self-imaging takes place. In order to obtain a focused beam outside the waveguide, we proposed that the length of the multimode waveguide to be set slightly shorter than the self-imaging length. In this way, after a propagation length of the order of one wavelength outside the waveguide facet, in air, the beam is focused. A scheme of the waveguide design is shown in Figure 1, where a single-mode rectangular waveguide is connected with a multi-mode rectangular waveguide. The material of the guide layer is SiN (n=2.05) and of the cladding layer is SiO2 (n=1.47). The thickness of the cladding (guide) layers are 1100 (800) nm for the multi-mode waveguide and 1120 (160) nm for the single-mode guide and the length of the multi-mode waveguide is 3.0 µm (1.05 µm shorter than the self-imaging length). In the design shown here, the width and thickness of the rectangular waveguide are equal. The width corresponds to the effective width, including the penetration depth. In order to be compatible with the new Blue-ray system, we use the wavelength of 400 nm and the multimode waveguide is excited with the TE mode (electric field vector parallel to the interface of guide layer and cladding layer) of the single mode waveguide. The field within the multimode waveguide and the self-imaging characteristics are shown in Ref. 13. The field inside the waveguide and at the guide-air interface is calculated using the

[*] hfwangx@yahoo.com

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computer program FIMMWAVE[15] and the field at a distance d from the waveguide facet in air is calculated with the spectrum propagation method.[16]

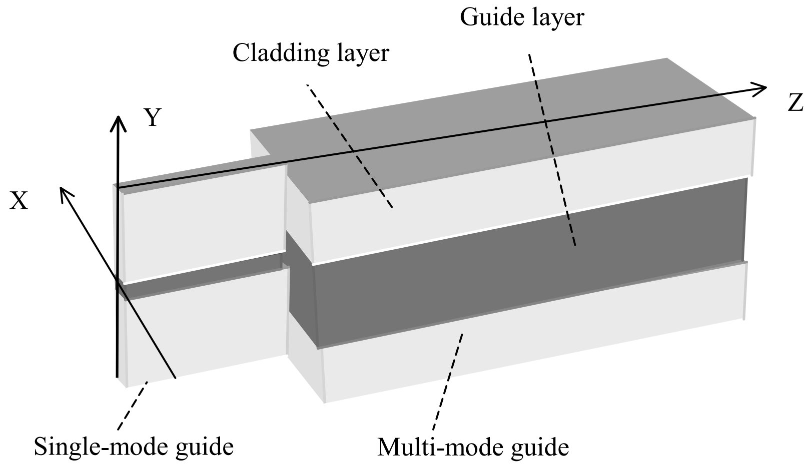

Fig.1 System structure

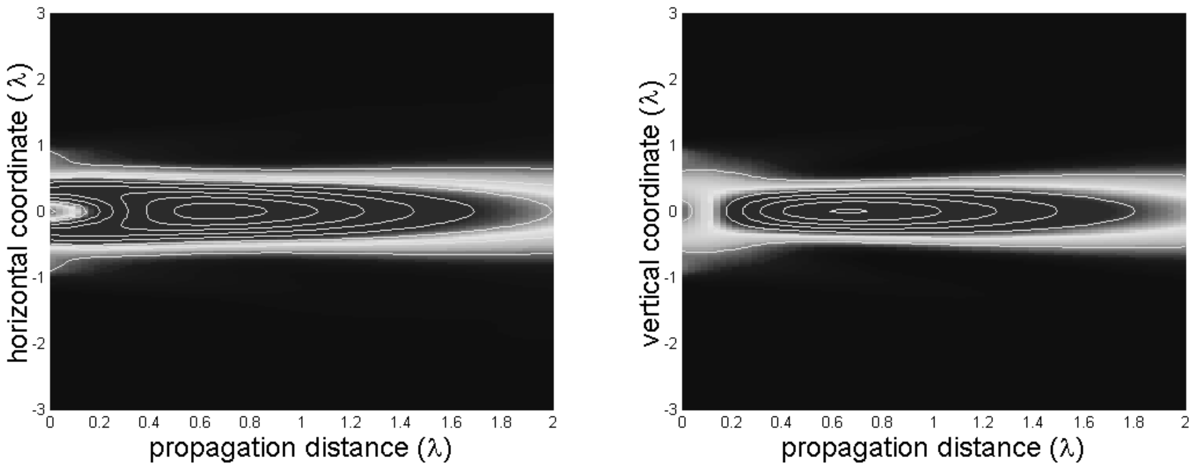

Figure 2: (a) horizontal and (b) vertical cross-sections of the field intensity outside the multimode waveguide. The focal plane is located at about 0.65 wavelengths from the wawaveguide facet (distance 0 in the figure)

The results of the simulations for the field outside the multimode waveguide are shown in figures 2a and 2b for the horizontal and vertical cross-sections, respectively. In this figure one can clearly see the focusing effect outside the multimode waveguide. For the parameters of the simulation, the focal plane occurs at 0.65 wavelengths away from the exit of the multimode waveguide, i.e., at 260 nm from the waveguide facet. The intensity profile at the focal plane of the focused beam is shown in Figure 3, and the full-width-at half-maximum of the intensity profile in the X-direction and

Y-directions are 0.77 and 0.57 wavelengths respectively. For comparison, in order to generate this spot with a focusing lens, it would correspond to a numerical aperture of 0.87.

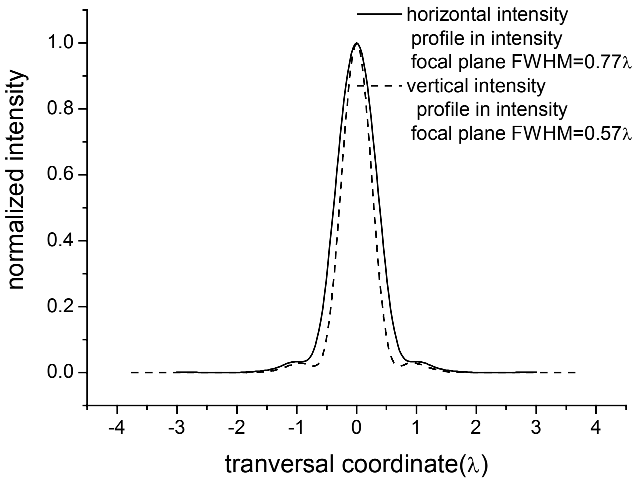

Figure 3: Intensity profile in the focal plane for the x (solid line) and y (dashed line) directions.

3. WAVEGUIDE LENSING SYSTEM AS PICKUP HEAD FOR OPTICAL RECORDING

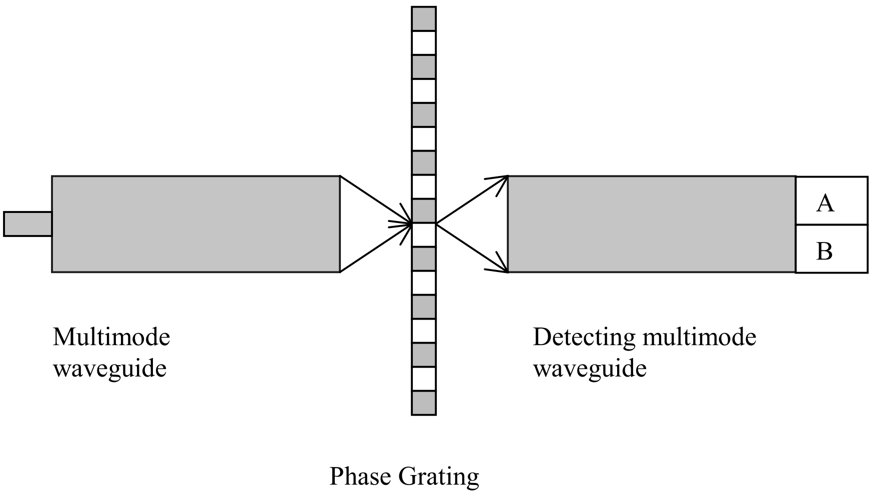

Figure 4: Scheme of the reading setup.

In order to test the reading capability of this focusing system, we set up a model shown in Figure 4. We place a one-dimensional phase grating at the focal plane of the focusing waveguide system, and at the other side of the grating we place an equivalent focusing system to detect the diffracted light. We calculated the interaction of the field with the grating by multiplying a periodic phase with the field, and then let the field propagate 0.65 wavelengths distance to the entrance of the detecting waveguide. The coupling into the multimode waveguide is calculated by overlapping the field with each waveguide mode and letting the guided modes propagate and superpose to obtain the total field within the waveguide. The forward propagating field is detected by a dual power detector, indicated as A and B in Fig. 4. The halfperiod of the grating is 0.3 wavelengths and the phase is π/2. We test the reading capability of the system by scanning the grating in the lateral direction and looking at the field intensity distribution at the back end of the detecting multimode waveguide for different positions of the grating. The initial position of the grating is shown in Fig. 4, and the subsequent positions are 11 steps, each step being 1/10 of the grating period. The intensity signals at the power detectors A minus B are calculated for each position of the grating and plotted in Figure 5. The modulation of the difference signal is clearly seen in the figure.

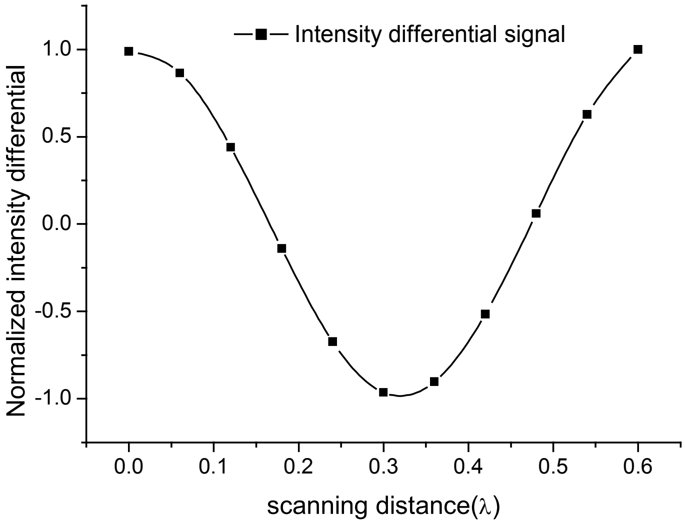

Figure 5: Difference intensity signal of the detectors A and B as one period of the grating is scanned.

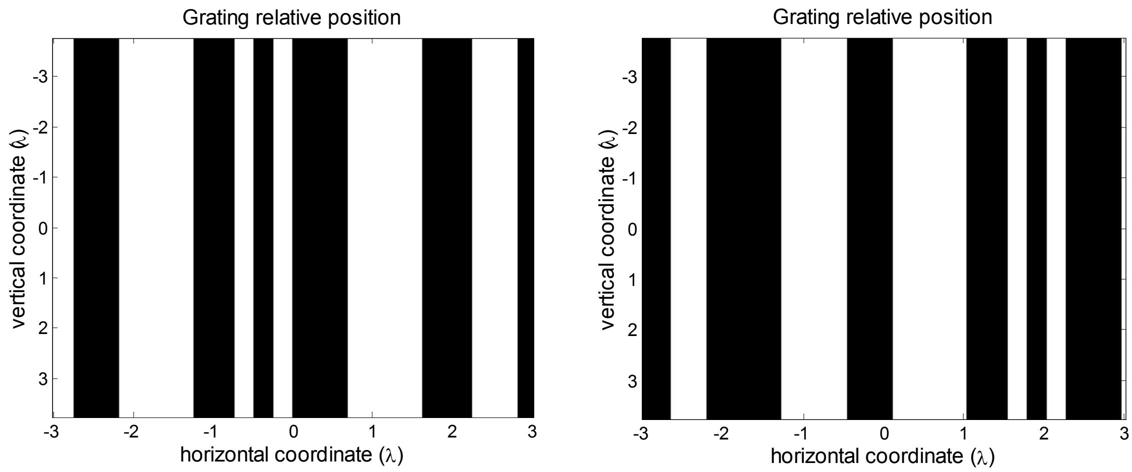

Figure 6: (a) start and (b) end positions of the scanning

By changing some of the parameters of the waveguide system, it is also possible to achieve super-resolution. This can be demonstrated here by making the waveguide length slightly longer, i.e., 3.4 μm in place of 3 μm.

The working distance is chosen to be 0.4 wavelengths away from the exit facet of the multimode waveguide, i.e. at the phase focal plane. The FWHM of intensity in the X- and Y-directions are 0.73 and 0.53 wavelengths, respectively. For the structure of the disk, we use the 3T to 14T encoding method, where the smallest 3T mark (or space) length is taken to be 0.24 wavelengths. As is shown in Figures 6a and 6b, we use the phase of $\pi/2$ to represent the mark (white stripes) and 0 (black stripes) to represent the spaces. Two marks with the smallest length 0.24 λ separated by 0.24 λ space is generated and the other marks (or spaces) are randomly generated from the 3T to 14T length. The sampling length in X- and Y-directions are 30.69 and 38.3625 wavelengths, respectively, and they are discretised into 1023*1023 cells. Figure 6a shows the start configuration and Figure 6b shows the end point of the scanning of the grating. The calculated difference intensity of the detectors placed at the end of the detecting multimode waveguide is shown in Figure 7. As can be seen in this figure, the profile of the difference intensity signal conforms to the structure of the marks scanned.

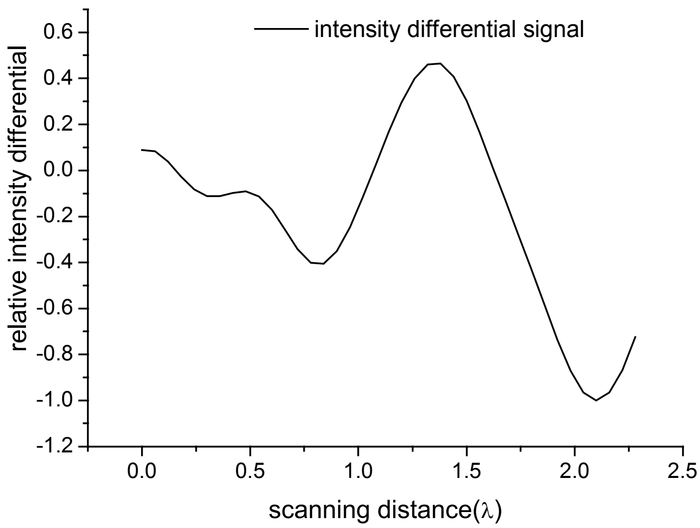

Figure 7: The difference intensity signal of the detectors A and B as the waveguide is scanned at a distance of 0.4 wavelengths of the sequence of marks shown in Figure 6.

3. CONCLUSIONS

We have demonstrated the reading capability of a specially designed multimode waveguide operated in the intermediate field. The modulation signal obtained by scanning a period and non-periodic gratings are shown, and for the latter configuration, modulation can still be seen for mark lengths as small as 0.24 wavelengths, which in the case considered in the simulation corresponds to 100 nm. Given the high resolution, the possibility of integration with illumination and detection systems, and the fact of being very compact, we believe that waveguide systems such as the one proposed is very promising for optical recording purposes. Another advantage of this system is that it should be straightforward to be extended to arrays, which will result in a very compact parallel optical pickup. The spot size and working distance can be set by changing the length of the multimode waveguide.[13]

4. ACKNOWLEDGEMENTS

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