Subwavelength optical detection using waveguides

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We present a study on the use of optical waveguides as read-out units for optical recording. The system consists in illuminating a set of bit patterns on a disc which are read by the waveguide. Due to particular properties of waveguides, which differ from a conventional optical lens, it is possible to achieve discrimination of bit patterns with densities corresponding to below the diffraction limit.

Introduction

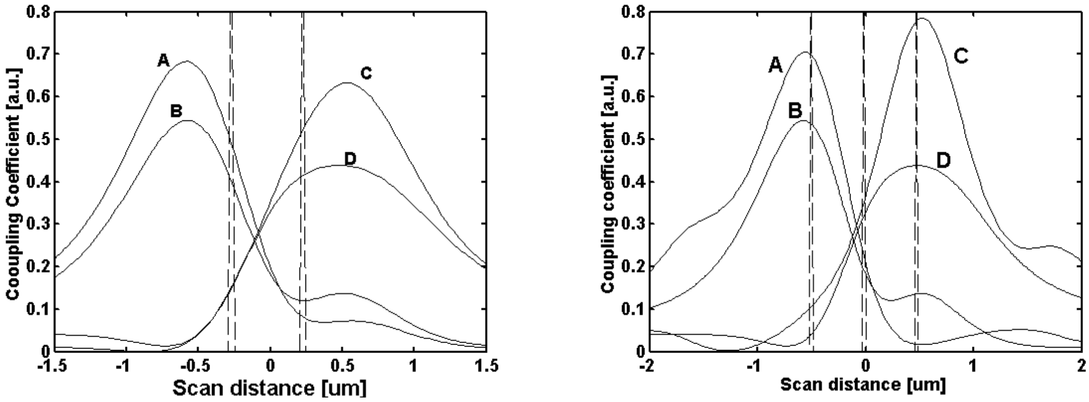
The demand for optical data storage systems with high information density is at the moment of considerable interest. An increase in information density beyond the recent developed Blu-Ray system is hampered by technical difficulties which involves laser wavelength in the ultraviolet region and extremely high numerical apertures. A new approach to detect information from an optical disc was suggested recently and involves the use of multimode optical waveguides in place of the lens to illuminate and read the optical disc[1,2]. In this system, the light from the waveguide illuminates an isolated binary bit pattern consisting of *n* bits on the optical disc. The separation between the bit patterns is smaller than the diffraction limit (half a wavelength) and the distance between waveguide and disc is of about 1-2 wavelengths. The light reflected from the bit pattern couples back to the waveguide and the coupling coefficients of the different modes of the waveguide is obtained as a function of its position with respect to the binary pattern. Depending on the bit pattern (2^n possible combinations for a group of *n* bits), the position dependent coupling coefficient of the zero and first orders of the waveguide will differ slightly. In Ref.2 it was suggested that high distinction between the various bit patterns could be obtained if the waveguide is scanned with a tilt with respect to the disc. According to simulations, it was concluded that distinction between bit patterns from five bits is possible even if the distance between the bits is of 0.25 wavelengths. This result shows that this system has potential to resolve bit patterns with size below the diffraction limit. The explanation behind it is that the tilted waveguide sees an asymmetric field and thus bits which are on the left and right side of the central bit couple differently into the waveguide so that no degeneracy will occur (as is the case of the waveguide without tilt). One drawback of the tilted waveguide is however the technical difficulty of scanning it at a very short distance from the disc. This problem led us to explore another possible designs, which could be easier to handle experimentally. The design we present here consists of two single mode waveguides set very near each other and the asymmetry is reached by making the width of one waveguide slightly smaller than the other one. Since the waveguides are very near each other it is possible to define two supermodes: the symmetric (TE0) and the anti-symmetric (TE1) modes. As in Ref.2, the marks on the disk are represented by a source array separated by a subwavelength distance. The light from the source array couples to the waveguide and the coupling coefficient into the two supermodes is calculated as a function of the position with respect to the bit pattern. The coupling coefficients are plotted as a function of the position for three different sets of bits, namely one, two or three bits separated by a distance of half a wavelength.

Theory

In our theoretical approach, we consider a system consisting of two single mode waveguides with widths of W_1 and W_2 that scans along arrays of bit patterns. In order to find the power of the light coupled into the mode *m* of the waveguide system one should calculate the coupling coefficient a_m which is given by $a_m(d) = \int_{system} E_s(x)E_m(x)dx$, where $E_s(x)$ is the field from an extended point sources, representing the bit patterns, at the end facet of the waveguide, $E_m(x)$ is the transverse field distribution of the mode *m* in the waveguide structure (*m*=0,1), $E_s(x)$ is the field from the point sources at the scanning heigth, and *d* is the scanning position of the structure with respect to the sources. The field of one bit pattern is given by the superposition of the fields due to separate point sources distributed along the bit length.

Results of the simulations

The optical scanning device was simulated with a MatLab program. In the program, the scanning height, widths of the waveguides W_1 and W_2, the refractive indices of the core and cladding, the distance between the waveguides, and the source distribution can be set in order to calculate the absolute value of the mode coupling coefficients (a_m), as described in the previous section. Here we show the calculated coupling coefficients as a function of the position (modal response curve) of the waveguide with respect to the sources for three cases: one, two and three bits. The distance between the bits were also varied. In the curves shown in Fig.1, the inter-source distance is 0.5 µm. In Fig.1a we show a comparison between the coupling coefficients of the TE0 and TE1 modes of the waveguides structure for the case of one (Fig.1a **B** and **D**) and two sources (Fig.1a **A** and **C**), respectively. In Fig.1b a similar comparison between one source (Fig.1b **B** and **D**) and three sources (Fig.1b **A** and **C**) is given. The simulation parameters are: refractive index of the core (cladding) of the waveguides is 3.5 (3.3), the distance between the waveguides is 630 nm, the widths W_1 = 392 nm and W_2 = 360 nm. Both the wavelength and the scanning height are set to 1 micron. From Fig.1 one can see that there is a clear distinction in the coupling coefficient between one and two (or three) bits for both modes TE0 and TE1. In order to quantify how distinct the coupling is, we concentrate at one particular scanning position, namely the position where the mode TE0 reaches its maximum. At this position we obtain the value of the coupling coefficient of the mode TE1 for the three situations, i.e., one, two and three point sources. One of the reasons that we have chosen for this fixed position is because the measurements can be easily made. In the case of Fig.1, the difference in value of the coupling coefficient of mode TE1 at this fixed position is 6.5% for one and two sources (Fig.1a) and 12% for one and three sources (Fig.1b).



(a) (b)

Figure 1: Modal response curves for the symmetric and anti-symmetric system modes of the dual waveguide system as a function of the displacement d for the case of (a) one and two point sources and (b) one and three point sources. For both cases the letters **A**, **B**, **C** *and* **D** *at the curves correspond to two (three) point sources mode TE1, one source mode TE1, two (three) sources mode TE0 and one source mode TE0. The distance between the point sources is 0.5 wavelengths and the scanning height is 1 micron (one wavelength).*

We have further analysed the same system using this fixed position of the coupling coefficient and changed the distance between the sources. In this way one can have an idea of the maximum resolution of the system once this particular measurement method is chosen. As expected, we see that the difference in the value of the coupling coefficient of mode TE1 becomes smaller as the distance between the sources gets smaller and diminishes faster for the case of one-two sources than for one-three sources. But it also interesting to see that if only this distinction method is considered (value of TE1 obtained where mode TE0 is maximum), the differences in both cases also diminishes as the distance between the sources becomes greater than 0.8 and 1 microns for the case of one-two and one-three sources, respectively. This happens because the shape of the response curve of the coupling coefficient changes and other distinction parameter should be defined. In any case, we conclude that if the distance between the sources varies between 0.3 and 0.5 microns, the above discussed distinction method can be used and the minimum difference is of the order of 2% for the case of one-two sources and 4% for one-three sources.

Conclusions

In conclusion we present a analysis of a dual waveguide system which could be used to detect bit patterns on an optical disc. This method relies on looking at the distinction in the coupling coefficient of the two supermodes of the system at a particular position of the waveguide with respect to the set of pits. The results show that by choosing one particular position of the waveguide which can be easily realised experimentally, distinctions between one-two and one-three point sources greater than 2% should be possible for distance between the sources varying from 0.3 to 0.5 wavelengths. This result clearly shows that resolution below the diffraction limit is possible and this system could become an attractive alternative for optical disc reading systems.

References

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