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WAVEGUIDE COMPUTER-GENERATED-HOLOGRAM ELEMENT

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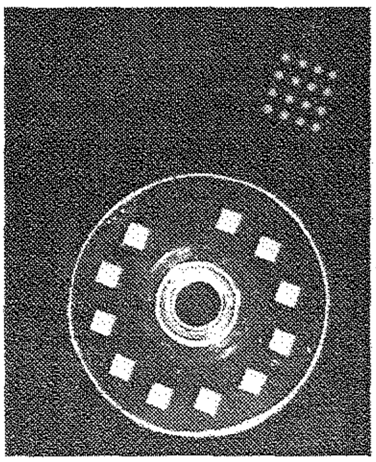
Abstract
Waveguide computer-generated-hologram elements are a new type of integrated optics components. Like their free-space counterparts, they extensively use the wave nature of light to control the propagation of light in a flexible way through diffraction. Their inherent multifunctionality can potentially be used in integrated optics devices to make them smaller, cheaper, more robust, and/or simpler to align and package.

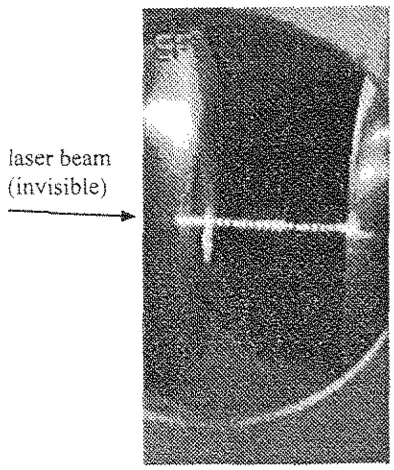
Introduction: free-space CGHs

In this introduction we take a brief look at free-space computer-generated-holograms (free-space CGHs) which have inspired the work on waveguide CGHs which will be described in the rest of the paper.
Free-space CGHs, where the light propagates in air before and after the CGH, are already an established photonic technology for controlling the propagation of light in a highly flexible way. More than other optical techniques, CGHs use the fact that light is a wave. CGHs are diffractive elements and work mainly by phase modulation of the light. The phase modulation function is complicated and is designed numerically with computers.
The past two decades' research on and applications of *free-space CGHs have shown that CGHs*

- are suitable for mass production since they are often realized as shallow surface reliefs. One example is fabrication by compact-disc replication techniques[1], see Fig. 1(a).
- can have a high efficiency (CGHs are often non-absorbing).
- can implement functions not obtainable with conventional optics[2].
- can be highly multifunctional: many functions can be included in one component which leads to small and robust optical systems with few components and lower costs for assembly and packaging. The multifunctionality is exemplified in Fig. 1(b) where a single CGH is producing 20 focal points along a line (the intensity in the foci becomes so high that a visible gas discharge is created locally).

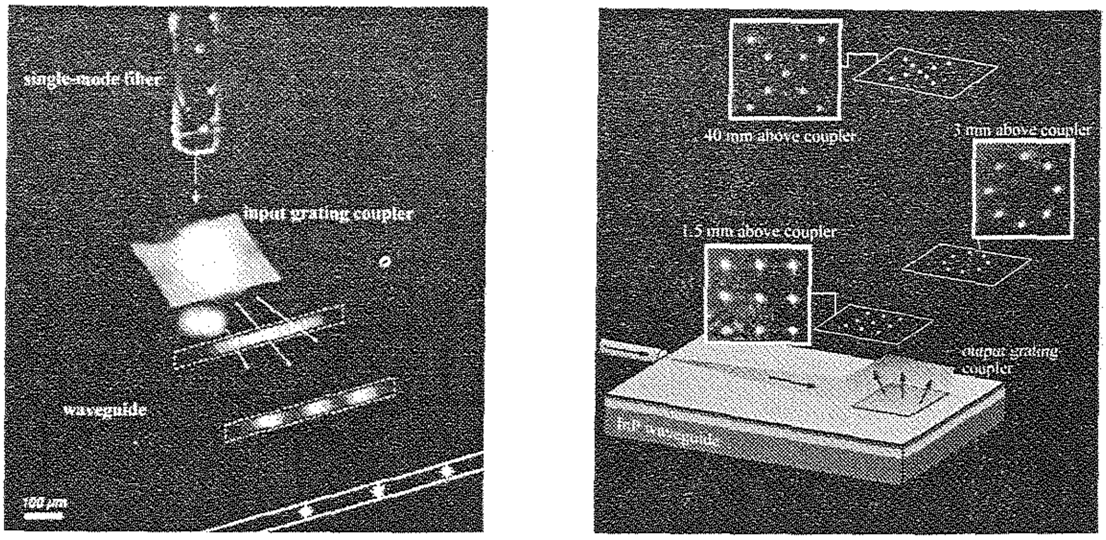


(a)



(b)

Fig. 1. Free-space CGHs: (a) replicated in polymer, (b) creating a plasma with a tailor-made spatial distribution (the CGH is hidden inside the left metal electrode where it is hit by a high power laser beam).



(a) (b)

Fig. 2. Waveguide CGHs: (a) Input grating coupler. (b) Output grating coupler.

Waveguide CGHs - a new type of integrated optics

The advantages of free-space CGHs have encouraged work on CGHs in waveguides. We have investigated waveguide CGHs in the form of so called *grating couplers*. They can perform functions similar to free-space CGHs but have an important additional function: the coupling of light from the waveguide into free-space or vice versa. Grating couplers can be used, e.g., as the interface between the main components (laser, fiber, and detectors) in the fiber optical communication network. The multifunctionality of the grating couplers reduces the complexity of the interface which leads to fewer processing steps in the fabrication and a simplified assembly of the optical system.

A grating coupler can be either incoupling or outcoupling. *Incoupling* is shown in Fig. 2(a). The basic function is to collect the incident light, in this case from the tip of an optical fiber, and launch it as a guided wave in the semiconductor waveguide. Used at the receiving end of an optical communication system, detectors can be integrated in the same semiconductor material for conversion of the optical signal to an electrical. *Outcoupling* is also possible as shown in Fig. 2(b). The figures also show that additional optical functions, such as focusing and beam-splitting, can be built into the couplers just as for free-space CGHs.

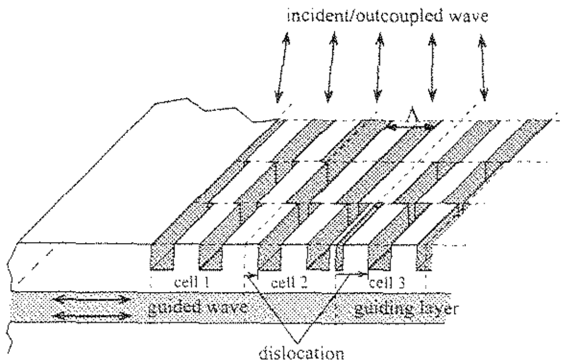


Fig. 3. Cellular grating structure of waveguide CGHs (in- or output grating couplers).

Waveguide CGH structure

The waveguide CGH is a structure etched into the surface of the waveguide. It consists of small portions of grating lines that together make up the entire coupler area. The local position of a grating line depends on the function that the coupler implements. In practice, to facilitate both the design and fabrication, the coupler area is divided into small square areas, cells, within which a number of grating lines are etched. The grating line separation, Λ, is constant in all cells but the grating lines in a cell as a whole can be shifted, or dislocated, which is shown in Fig. 3. It is the dislocation that imposes the phase modulation of the light and enables the high functionality[3].

Examples of waveguide CGHs

a) Incoupling with complex launch schemes

It is possible to design the couplers for launching the incoupled light both "forward" and "backward" at the same time as focusing and beam-splitting is imposed on the guided wave[4]. This is a compact method to send light into opposite directions in a photonic integrated circuit. Figure 4 shows the simulated performance of such a coupler and photographs taken of both edges of the waveguide showing that the desired functions were obtained.

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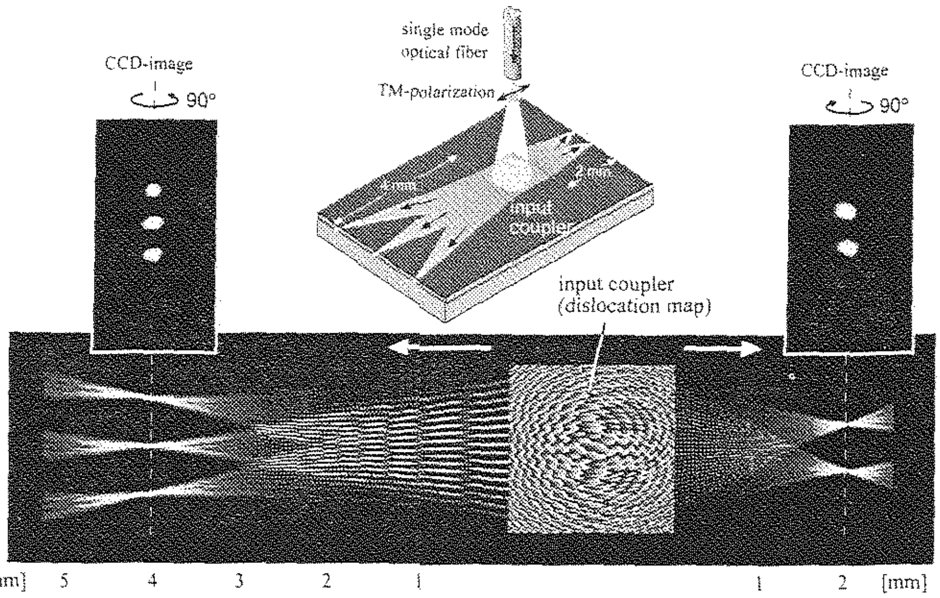

Fig. 4. Simulated and experimental performance of input coupler with bidirectional launching.

b) Incoupling with polarization independence

In fiber communication, the output from the fiber in most cases has an unknown state of polarization. Therefore it is often highly desirable to make the input grating couplers function independently of the polarization. Generally, grating couplers are highly polarization sensitive but with the new design it is possible to obtain almost complete polarization independence, see Fig. 5.

c) Incoupling with WDM capability

Input couplers that separate and focus the incident light to different positions have been designed and fabricated.[5] One example is shown in Fig. 6 where the channel separation is 10 nm. A similar experiment was made with a coupler having a 2 nm channel separation. This separation is of interest, e.g., in local area (access) optical networks and is sometimes referred to as "coarse WDM".

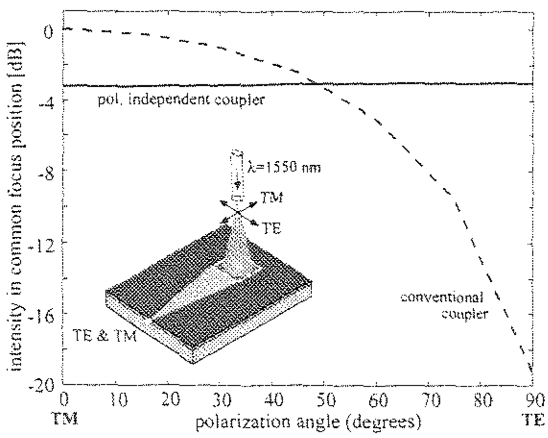

Fig. 5. Measured polarization response of the input coupler designed for polarization independence (solid line) and for a conventional grating coupler (dashed line).

d) Outcoupling: "Laser system on a chip"

Output grating couplers have been integrated with in-plane semiconductor lasers to form monolithic and highly functional laser sources, see Fig. 7, in this example to produce the intensity distribution of the stellar constellation Big Dipper (Ursa Major) at some distance above the waveguide surface. Unfortunately, the more complex output gratings also give a more complex feedback which cannot be avoided with simple wavelength detuning as for regular output gratings. The upper right figure shows that the feedback is focused into rays with high intensity in the gain section which disturbs the laser and leads to the output becoming distorted as is seen in the upper left figure. We are currently working on an output coupler design that gives a desired feedback as well as output. By designing for reduced feedback we hope to obtain near diffraction limited output. By instead designing for controlled feedback into the cavity, the output coupler can also work as a sophisticated feedback grating potentially giving a laser source with unique properties.

Conclusion

Waveguide computer generated holograms are diffractive elements that more than most optical waveguide elements make use of the wave nature of light. In this way they can perform a number of functions simultaneously and still have a small size. There are still problems to be solved before these components become commercially attractive: especially for the input couplers, the efficiency has so far been very low (of the order of one or a few percent). The present research is, among other things, directed toward increasing the efficiency by using an optimized grating structure.

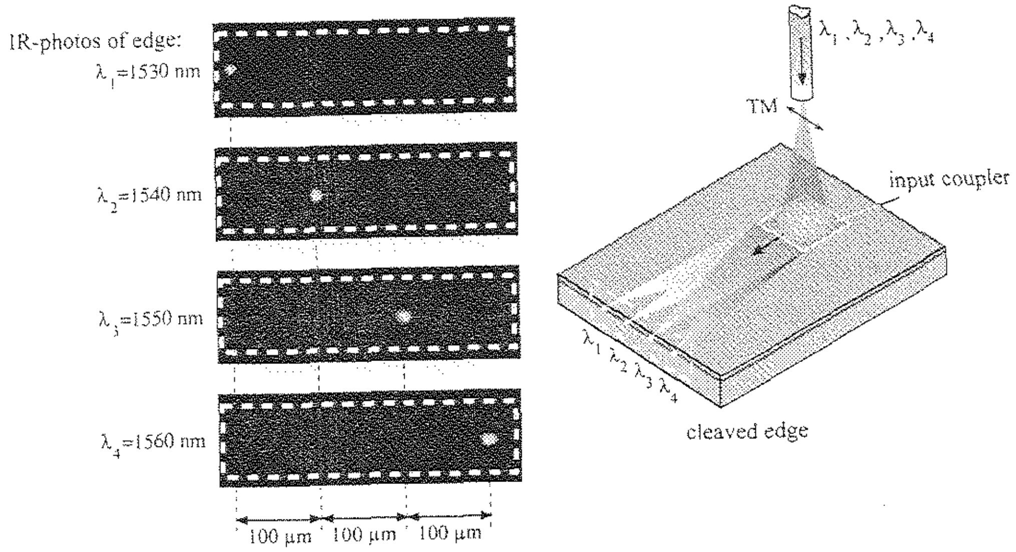

Fig. 6. Experimental results of an input grating coupler implementing wavelength division demultiplexing.

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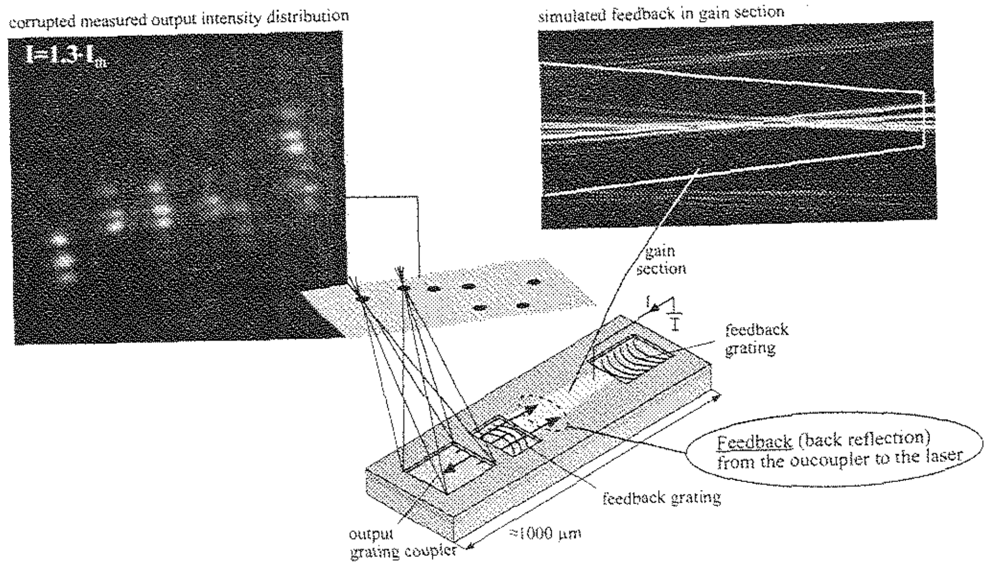

Fig. 7. Simulated and experimental effects of uncontrolled feedback from the waveguide CGH when integrated to form a monolithic laser-system-on-a-chip.