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# Observation of the Discrete Talbot Effect

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**Abstract:** We report the first observation of the discrete Talbot effect in one-dimensional waveguide arrays. Recurrence for different input patterns was observed in very good agreement with simulations. No recursion occurs for the zero diffraction direction.

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The repeated self-imaging of a periodic light pattern, better known as the Talbot effect, is among the most fundamental phenomena associated with the process of diffraction. This effect was first observed by Talbot in 1836 [1] and it was explained by Lord Rayleigh fifty years later [2]. Briefly speaking, the Talbot effect arises from the coherent recombination of the spatial harmonics of the initial periodic optical pattern. In the paraxial diffraction regime, the image of such pattern perfectly reappears during propagation at integer multiples of the so-called Talbot distance $Z_T = 2D^2/\lambda$, where $D$ is the pattern periodicity and $\lambda$ is the wavelength. Quite recently the physics of discrete systems has received considerable attention. In optics, arrays of weakly coupled waveguide provide a fertile ground for experimental investigation of discrete phenomena [3]. What makes such discrete systems different from their continuous counterparts is the very origin of diffraction. Discrete diffraction occurs via weak coupling between adjacent channels and exhibits a periodic dispersion behavior in k-space. The question of course arises as to whether a "discrete" Talbot effect exists and if so how does it differ from the well understood continuous case. Here we report the experimental observation of the Talbot effect in discrete waveguide arrays.

In general the modal field amplitudes in waveguide lattices evolve according to

$$i\frac{da_n}{dz} + c(a_{n-1} + a_{n+1}) = 0$$

where $a_n$ is the complex field amplitude in the n-th channel (coupled to its nearest neighbors), $c=\pi/2L_c$ is the inter-channel coupling constant and $L_c$ the half-beat coupling length. Figures 1 depict the resulting intensity patterns (as viewed from the top) as a function of propagation distance when the waveguide array is excited with a spatially periodic input. The figure on the left was generated with a {1, 0, 1, 0, …} input whereas that on the right with a {1, 0, 0, 1, 0, 0, …} sequence. In both cases a "carpet" appears, i.e. the input pattern repeats periodically.

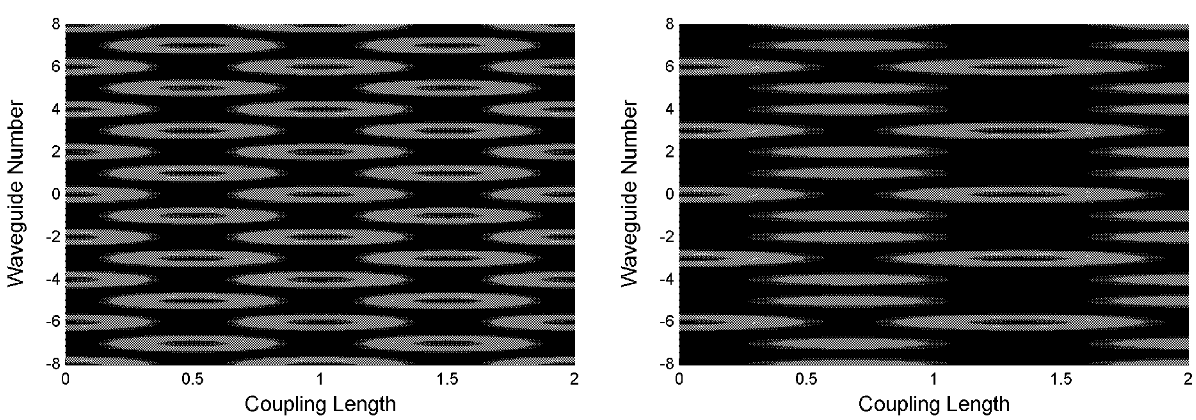


Fig. 1. Simulated pattern evolution for {1, 0, 1, 0, …} left-hand-side and {1, 0, 0, 1, 0, 0, …} right-hand-side input patterns.

Channel waveguide arrays (each consisting of 101 guides) were fabricated on 70mm long Z-cut LiNbO3 wafers using standard lithography techniques by Ti-indiffusion. The center-to-center spacing between the arrays' channels varied from 14 to 16 μm. The coupling length was measured experimentally as a function of wavelength by fitting single channel excitation diffraction patterns to the formula:

$$a_n(z) = (i)^n J_n(2cz)$$

where $J_n$ represents a Bessel function of n-th order. The coupling length vs. wavelength is shown in Fig. 2 for various array designs.

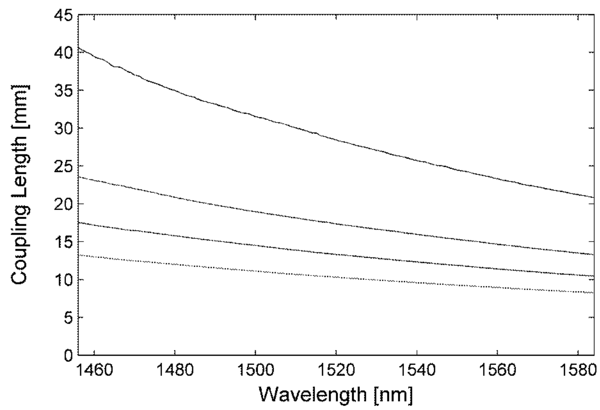


Fig. 2. Coupling length of four arrays with different channel-to-channel separation as function of wavelength.

In our experimental setup we used a tunable diode laser HP81680. The beam was shaped to be highly elliptical in shape (420×3μm) using a telescope and focused by a 10X microscope objective onto the input facet of the sample. (see Fig. 3) Amplitude transmission masks, with periodicities equal to multiples of the periodicity of the arrays and different patterns, were fabricated using laser writing and etching techniques. The masks were put in contact with the sample for clean in-phase mode excitation. To control the tilt of the input beam and hence the initial phase difference between adjacent channels, a mirror on a motorized stage was placed in front of the microscope objective. Because of the sample's excellent linear properties (low scattering) we were not able to observe the recurrence of the pattern looking from the top. However, we were able to indirectly observe the Talbot process at the output of the array by tuning the wavelength and hence the coupling length over the full range of the laser (1456-1584nm). This corresponds to an effective sample length change for the Talbot effect and at the same time it didn't affect diffraction properties of the finite beam.

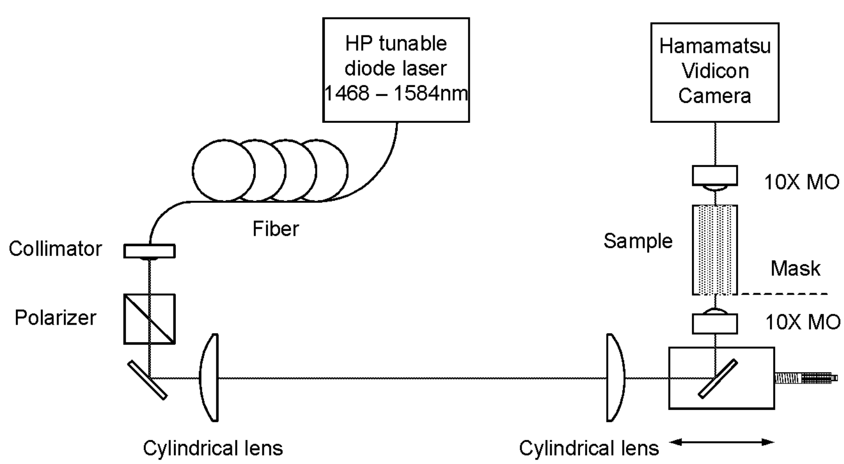


Fig. 3. Experimental setup.

The experimental results corresponding to the periodic {1, 0, 1, 0,…} and {1, 0, 0, 1, 0, 0,…} excitation conditions simulated in Figure 1 are shown in Figure 4. In particular Figures 4 depict the intensity at the output of the array as a function of wavelength. The agreement is excellent. The "wavy" nature of the observed patterns is a consequence of the wavelength tuning which introduces wavefront curvature at the input facet due to dispersion in the optical elements, i.e. the focal point shifts with wavelength. This introduces a weak excitation of higher order bands which interfere with the lowest order band of interest. Additional experiments were performed for the excitation conditions {1, 0, 0, 0, 1, 0, 0, 0, …} and again excellent agreement with theory was found.

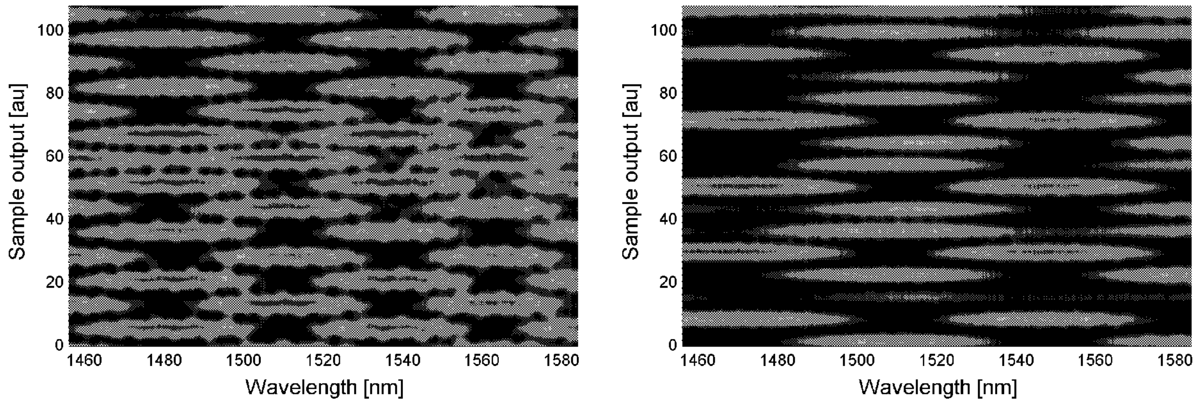


Fig. 4. Experimental results with input patterns {1, 0, 1, 0, …} and {1, 0, 0, 1, 0, 0, …}.

In contrast to bulk media in which the diffraction coefficient is a constant, the strength of the diffraction can be controlled by introducing a relative phase shift at the input between adjacent channels [4]. At a phase difference of $\pi/2$, the diffraction goes to zero and therefore no recursion pattern occurs, as shown in Figure 5.

Experiments were performed by tilting the input beam. As shown in Figure 5, the periodic recursion disappears for this case. The results are not as clean as in the simulations because of changing conditions of the initial beam tilt as a function of wavelength – for complete suppression of the Talbot effect the exact $\pi/2$ initial phase difference is required. Nevertheless, it is clear that in the discrete regime the Talbot recursion does not occur.

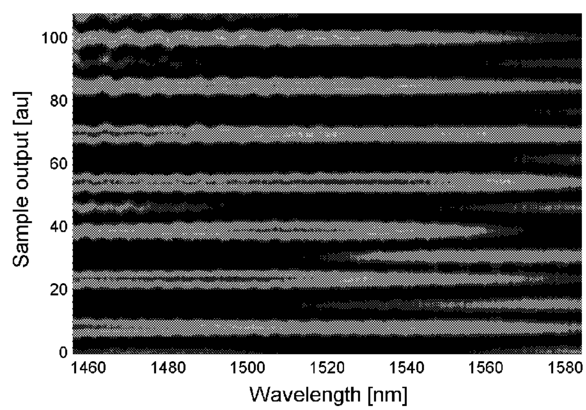


Fig. 5. Experimental results with input pattern {1, 0, 1, 0, …} and diffractionless angle ($\pi/2$ phase shift between adjacent channels).

In summary, we have demonstrated the existence of a discrete Talbot effect in arrays of weakly coupled waveguides. Experiments and theory are in excellent agreement. Among the unique features of the discrete Talbot is the fact that there are directions of propagation in which no recursion occurs (the Talbot effect disappears).

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## References

1. F. Talbot, "Facts relating to optical sciences No. IV," Philos. Mag. 9, 401-407 (1836).
2. L. Rayleigh, "On copying diffraction-gratings, and on some phenomenon connected therewith," Philos. Mag. 11. 196-205 (1881).
3. D. N. Christodoulides, F. Lederer and Y. Silberberg, "Discretizing light behaviour in linear and nonlinear waveguide lattices," Nature 424 (6950), 817-823 (2003).
4. H. S. Eisenberg, Y. Silberberg, R. Morandotti and J. S. Aitchison, "Diffraction management," Phys. Rev. Lett. 85 (9), 1863-1866 (2000).