Discrete Talbot Effect

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The repeated self-imaging of a diffraction grating—a classical effect in optics—was first reported by Talbot in 1836.[1] Lord Rayleigh explained this remarkable phenomenon a few decades later when he showed that any periodic one-dimensional field pattern reappears, upon propagation, at even integer multiples of the so-called Talbot distance $z_T = D^2/\lambda$, where D represents the spatial period of the pattern and λ is the light wavelength. In addition to the integer Talbot effect, fractional as well as fractal revivals are also known to occur at distances that are rational or irrational multiples of z_T, respectively.[2]

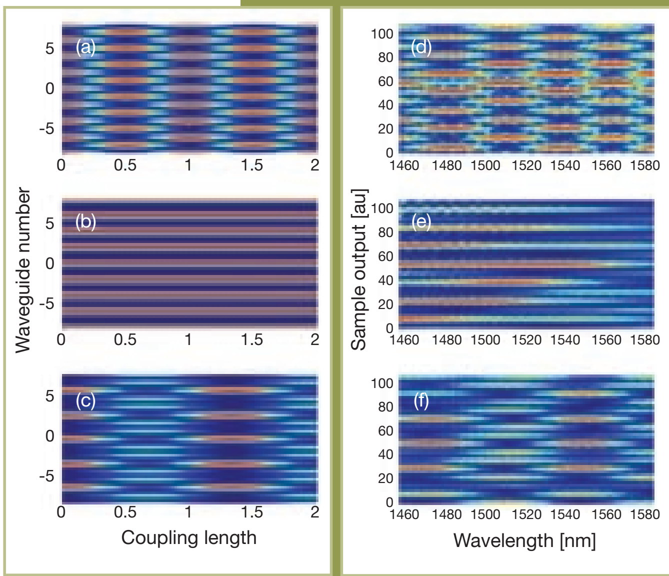
Lately, the optical research community has shown considerable interest in wave propagation phenomena in discrete structures. Arrays or lattices of evanescently coupled waveguides or chains of coupled microresonators are prime examples of structures where discrete optical wave dynamics can be observed.[3] One question that has naturally arisen is whether the Talbot effect is also possible in discrete systems.

We have recently reported the first experimental observation of discrete Talbot effects in weakly coupled waveguide arrays.[4] We found that, unlike in continuous systems where the Talbot self-imaging effect always occurs irrespective of the pattern period, in discrete configurations this process is only possible for a specific set of periodicities N. In discrete structures, the periodicities leading to discrete Talbot revivals are those for which the cosine of $\cos(2\pi/N)$ is a rational number. This is only possible when the period N of the initial pattern belongs to the set $\{1,2,3,4,6\}$.

The left column of the figure depicts the theoretically anticipated Talbot intensity patterns (as viewed from the top) as a function of propagation distance or coupling length when the waveguide array is excited with a spatially periodic input. Parts (a), (b) and (c) were obtained using a {1, 0, 1, 0, …},{1, 0, -1, 0, ... } and a {1, 0, 0, 1, 0, 0, …} periodic input, respectively. In all cases, a "carpet" appears—in other words, the input pattern repeats periodically.

The absence of any revivals in (b) is due to the fact that the {1, 0, -1, 0, ... } pattern excites the lattice at the middle of the Brillouin zone (at $\pi/2$), where the effective diffraction of the array is zero,[5] and so the Talbot process that derives from this effect vanishes. To demonstrate discrete Talbot effects, we used a channel waveguide array consisting of 101 guides, fabricated on 70-mm-long Z-cut $LiNbO_3$. Because of the sample's excellent linear properties (low scattering), we were not able to observe the Talbot revivals when looking from the top.

Instead, indirect observation of the Talbot process at the output of the array was possible. We accomplished this by varying the wavelength (and hence the coupling length) over the full spectral range of the probing semiconductor laser (1456 to 1584 nm). This change in coupling strength with wavelength is essentially equivalent to varying the effective sample length. Amplitude masks were also used to excite the array with a periodic input. The experimental results corresponding to the excitation conditions simulated in (a), (b) and (c) are shown in (d), (e) and (f). In these figures, the intensity at the output of the array is shown as a function of wavelength. The experimental results agreed well with theory.



Talbot intensity "carpets" as a function of propagation distance for different periodic input field patterns: (a) {1, 0, 1, 0, ... }, (b) {1, 0, -1, 0, ... }, (c) {1, 0, 0, 1, 0, 0, ... }. Experimental results corresponding to the excitation conditions simulated in (a), (b) and (c) are shown in (d), (e) and (f). In the latter set of figures, the intensity at the output of the array is shown as a function of wavelength.

In conclusion, we have observed for the first time discrete Talbot revivals in waveguide arrays. Unlike continuous systems, where the Talbot self-imaging effect always occurs irrespective of the pattern period, in discrete configurations this process is only possible for a specific set of periodicities.

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