Observation of Landau-Zener tunnelling in hexagonal photonic lattices

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Abstract: *We present the first experimental studies of the Landau-Zener tunneling dynamics in hexagonal photonic lattices and demonstrate that in realistic systems the tunneling efficiency strongly depends on the initial conditions and may differ dramatically from that in ideal systems.*

Electrons in crystalline solids or semiconductor superlattices, cold atoms in optical lattices, light beams in photonic crystals or waveguide arrays have the energies confined to Bloch bands separated by band gaps. The system response to a weak linear potential (i.e., a weak constant tilt) manifests itself in the form of Bloch oscillations as well as interband transitions known as Landau-Zener tunnelling. While the majority of previous studies considered only one-dimensional systems, in a recent experiment the interband transitions have been observed for the first time in a two-dimensional periodic structure of square symmetry [1].

Multi-dimensional optical lattices are also routinely used for trapping of ultracold atoms and condensates of degenerate quantum gases, where more sophisticated trapping geometries have been shown experimentally. Simple theories are especially important for understanding the wave dynamics in the periodic structures and the theory of Zener tunnelling in hexagonal photonic lattices has recently been developed [2, 3].

In this work we report on the experimental observation of Landau-Zener tunnelling in optically induced hexagonal photonic lattices by studying symmetric [2] and asymmetric [3] three-fold resonances. Because of the fixed length of the photorefractive crystal, we trace the dynamics of the propagating beam by changing the input tilt angle of the probe Gaussian beam, i.e. its initial position in Fourier space relative to the high-symmetry resonance points in the first Brillouin zone. In both cases we are able to observe the oscillatory character of the resonant transitions by measuring the relative powers of the output beams in the far-field (reciprocal space) against input angle.

As an example, Figure 1 shows the Fourier space output of a Gaussian probe beam

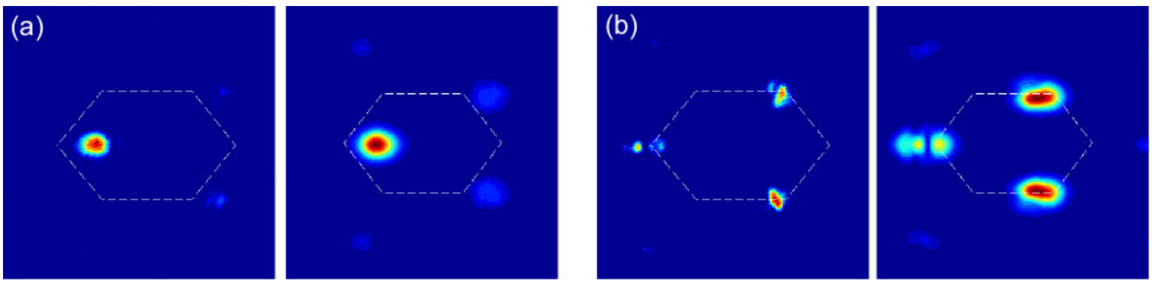

Figure 1: Experimental (left panel) and numerical (right panel) Fourier space output of a Gaussian probe beam for different input angles: (a) α=0.02°; (b) α=0.40°.

input for two different input angles. It is clearly visible that the relative power of the resonant beams, i.e. the tunnelling efficiency strongly depends on the input condition.

Optically induced photonic lattices in photorefractive media are known to posses strong anisotropic features which may change the symmetry of the induced refractive index pattern [4] and consequently affect the efficiency of tunnelling. In experiments the anisotropy of the lattice can be compensated by stretching the lattice along its vertical direction to achieve a refractive index pattern having an effectively symmetric hexagonal structure [5].
The experimental results are corroborated by numerical simulations using the full anisotropic photorefractive model. We consider the propagation of realistic finite-size beams in a stretched hexagonal lattice and, similar to the experiment, determine the relative powers of the output beams in the far-field for different input angles. The observed behaviour of the Landau-Zener transitions is in a good qualitative agreement with our experiments.

Conclusions

In conclusion, we have studied Landau-Zener tunnelling in two-dimensional optically induced hexagonal photonic lattices experimentally as well as numerically.

Both, numerical and experimental studies clearly reveal that the propagation dynamics and the tunnelling efficiency of optical beams in realistic systems strongly depend on initial conditions and may differ significantly from the results obtained in ideal theoretical systems.

We believe that the present results provide an important knowledge to the understanding of the effects of Bloch oscillations and Zener tunneling not only in photonic lattices, but also in crystalline materials and cold atoms in periodic potentials.

References

[1] H. Trompeter, W. Krolikowski, D. N. Neshev, A. S. Desyatnikov, A. A. Sukhorukov, Yu. S. Kivshar, T. Pertsch, U. Peschel, and F. Lederer, Phys. Rev. Lett. **96**, 053903 (2006).
[2] A. S. Desyatnikov, Yu. S. Kivshar, V. S. Shchesnovich, S. B. Cavalcanti, and J. M. Hickmann, Opt. Lett. **32**, 325 (2007).
[3] V. S. Shchesnovich, A. S. Desyatnikov, and Yu. S. Kivshar, Opt. Express **16**, 14076 (2008).
[4] A. S. Desyatnikov, D. N. Neshev, N. Sagemerten, D. Träger, J. Jägers, Y. V. Kartashov, C. Denz, and Yu. S. Kivshar, Opt. Lett. **30**, 869 (2005).
[5] B. Terhalle, T. Richter, A. S. Desyatnikov, D. N. Neshev, W. Krolikowski, F. Kaiser, C. Denz, and Yu. S. Kivshar, Phys. Rev. Lett. **101**, 013903 (2008).