Anderson Localization In Optical Mesh Lattices Realized In Time Domain

Ilya D. Vatnik[1,2], Alexey M. Tikan[2], Dmitry V. Churkin[1,2,3], Andrey A. Sukhorukov[4]

1. Institute of Automation and Electrometry SB RAS, 1 Ac. Koptyug ave., Novosibirsk, 630090, Russia

2. Novosibirsk State University, 2 Pirogova str., Novosibirsk, 630090, Russia

3. Aston Institute of Photonic Technologies, Aston University, Birmingham, B4 7ET, UK

4. Nonlinear Physics Centre, Research School of Physics and Engineering, Australian National University, Canberra, ACT 2601, Australia

Recently, a fiber optic based implementation of mesh lattices was proposed [1,2], where discrete time-domain evolution of light pulses is realized. In this system practically arbitrary complex optical potentials can be realized, which opens the possibility to emulate various quantum physics phenomena for optical pulses. Recently, a number of important effects have been demonstrated in synthetic photonic lattices, including random walks of single particles [1], Bloch oscillations and unidirectional invisibility associated with parity-time symmetry [2], scattering on defect states [3], and demonstration of diametric drive acceleration [4]. Here we experimentally demonstrate Anderson localization in a static disordered potential realised in a time-domain optical fiber-based mesh lattice.

The synthetic photonic lattice is formed by two fiber loops with slightly different lengths connected by a 50:50 coupler. Optical losses in the loops are precisely compensated by amplifiers. We inject a single pulse, which produces a pulse train circulating in both loops. Every pulse of the train is defined by two discrete numbers. The number of roundtrips m corresponds to a “time” coordinate. The “space” coordinate n defines a ratio of the pulse delay time to the round-trip time difference between the two fiber loops.

Applying the phase shift ϕ_n which is random over n and constant over m, the optical analogue of a random potential can be created. As initial conditions we use a single pulse coupled at n=0 into the long loop, i.e. U_0=1 and V_0=0. In a regular lattice with no phase shifts ($\phi_{max} = 0$), the wavepacket expands in n space proportionally to the increase of m, similar to a quantum walk [1]. For a random potential, the wavepacket starts is localized over n, see Fig. 1(a). In experiments, we make averaging over different realizations of the random potential of the same strength, ϕ_{max}. In addition, we repeat experiments for different ϕ_{max}. Large ϕ_{max} correspond to stronger potentials and stronger localization. In our experiments we checked that the wavefunction develops exponential profile over n, consistent with Anderson localisation regime [5].

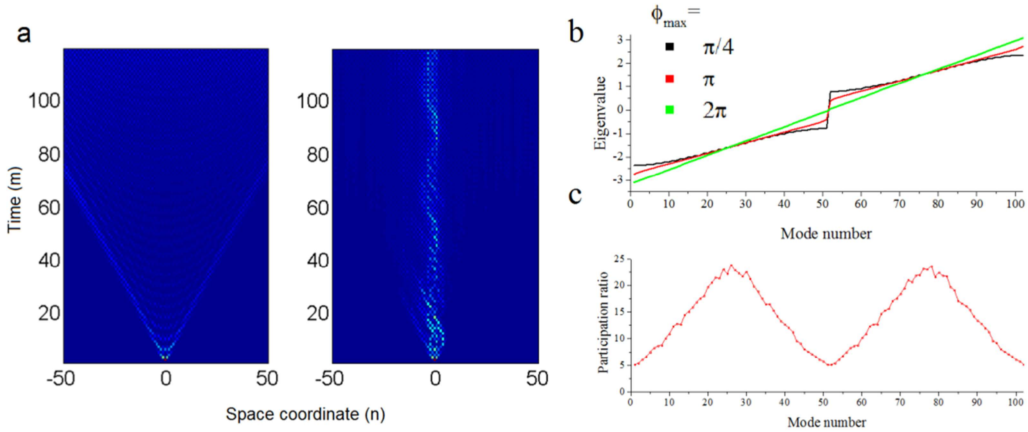

Fig. 1. (a) Experimentally measured evolution of a wavepacket over time without (left) and with (right) random potential; (b) Numerically calculated spectrum of modes for different potential strengths; (c) Numerically calculated participation ratio ($\sim \sigma^{-1/2}$) for the random potential of strength $\phi_{max} = \pi$.

We numerically calculate the eigenmodes for different potential strengths, and present the spectra in Fig. 1(b). In a regular lattice, there are two bands separated by a band-gap even if no potential is applised. The band-gap becomes narrower as the random potential becomes stronger, and the gap essentially disappears when the potential modulation approaches $\phi_{max} = 2\pi$. On the other hand, in agreement with previous studies [5], we find that the modes located near the edges of the band-gap are more localized in space n [Fig. 1(c)].

To conclude, the Anderson localization in an optical mesh lattice realised in time-domain is experimentally demonstrated. Interplay of photonic band-gaps and disorder in such lattices leads to stronger localization at band edges and gap closure for a strong disorder.

References

[1] A. Regensburger, C. Bersch, B. Hinrichs, G. Onishchukov, A. Schreiber, C. Silberhorn, U. Peschel, Phys. Rev. Lett. **107**, 233902 (2011).

[2] A. Regensburger, C. Bersch, M. Miri, G. Onishchukov, D. N. Christodoulides, and U. Peschel, Nature **488**, 167 (2012).

[3] A. Regensburger *et al.*, Phys. Rev. Lett. **110**, 223902 (2013).

[4] M. Wimmer *et al.*, Nat. Phys. **9**, 780 (2013).

[5] T. Schwartz *et al.*, *Nature* **446,** 52 (2007); Y Lahini *et al.*, Phys. Rev. Lett. 100, 013906 (2008).

978-1-4673-7475-0/15/$31.00 ©2015 IEEE