Controlled Unidirectional Reflection in Atomic Lattices of Parity-Time Anti-symmetry

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ABSTRACT

Artificial optical materials have attracted great attentions in the past few decades for achieving various properties and functionalities not available in the natural media. Photonic crystals and left-handed materials are two prominent meta-materials promising the possibility of stretching usual rules and displaying new paradigms of light propagation and interaction. They have been exploited to design and realize various all-optical, optoelectronic, and opto-mechanical devices, though cannot be directly used to implement unidirectional light transport, a more difficult task than others. Only in recent years significant progresses have been made by considering moving photonic crystals of cold atoms and solid materials with parity-time (PT) symmetry. As compared to traditional photonic crystals, PT-symmetric materials are periodically modulated not only in terms of real parts but also imaginary parts of refractive indices, exhibiting a delicate balance of gain and loss alternately along the modulation direction with n(z)=n*(-z). Very recently, PT-anti-symmetric materials are also considered, which require a more involved balance of positive and negative real refractive indices with n(z)=-n*(-z) instead. Here we assume that cold 87Rb atoms trapped in 1D optical lattices - whose density modulation is dominated by a COSINE term - are driven into the four-level N configuration with a far-detuned dressing field applied to induce the dynamic shift of one ground level. We find that a probe field may experience the PT-anti-symmetric susceptibility with chi(z)=-chi*(-z) when this dressing field has a traveling-wave (TW) and a standing-wave (SW) component so that the dynamic frequency shift is modulated as a SINE function along the lattice direction. That is, real and imaginary parts of the probe susceptibility are, respectively, an odd and an even function of the lattice position in each dipole trap. This dressing field modulation destroys the two-photon resonance condition between the probe and coupling fields in the regime of electromagnetically induced transparency (EIT) and we consider indeed passive atomic lattices with essential absorptive loss. Such optical PT-anti-symmetry then allows us to observe high-contrast unbalanced reflectivities and even fully unidirectional reflection with finite transmission at one NH-degeneracy point. It is of special interest that (i) a vanishing probe reflectivity at the probe resonance can be switched between the two lattice ends by changing the detuning signs of both TW and SW dressing components; (ii) fully unidirectional reflection can be attained even out of the probe resonance when the dynamic frequency shift deviates from a SINE function of the lattice position. Last but not least, both PT-anti-symmetric susceptibility and unidirectional light reflection depend also critically on the dynamically controlled Gaussian density distribution in each dipole trap.

[1] Jin-Hui Wu, M. Artoni, and G. C. La Rocca, Phys. Rev. Lett. 113, 123004 (2014). [2] Jin-Hui Wu, M. Artoni, and G. C. La Rocca, Phys. Rev. A 91, 033811 (2015).