Effect Of Spin-Orbit Coupling On Mobility Edges In One-Dimensional Non-Hermitian Quasicrystals

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Abstract

The investigations on delocalization-localization (DL) transitions in lower dimensions have been of interest to many researchers ever since the first work by Anderson on lattices with random disorders. In contrast to one-dimensional random lattices, where all the electronic states are localized even for an arbitrarily weak disorder, one-dimensional quasicrystals with nearest neighbour hopping shows a delocalization-localization transition at a critical disorder strength of the underlying quasiperiodic potential. However, there are no mobility edge in this system. Interestingly, the non-Hermitian one-dimensional quasicrystals having short range hopping, controlled by the exponential decay parameter p, shows existence of delocalization-localization transition as well as mobility edges. In this study, we explore the aforementioned one-dimensional quasicrystal in the presence of Rashba Spin Orbit (RSO) coupling, and demonstrate that with the increase in the RSO coupling strength the mobility edge behaves similar to the this system for larger value of the parameter p and without the RSO coupling.

Model Hamiltonian

One dimensional modified short range non-Hermitian Aubry-André Harper (AAH) Hamiltonian reads as,

$$H_{AA} = -t \sum_{n \neq n\prime, \sigma} e^{-p|n-n\prime|}(c^\dagger_{n\prime,\sigma} c_{n,\sigma} + h.c.) + \sum_{n,\sigma} V_n c^\dagger_{n,\sigma} c_{n,\sigma},$$

$$H_{RSO} = -a_z \sum_{n,\sigma,\sigma'} (c^\dagger_{n+1,\sigma}(i\sigma_y)_{\sigma,\sigma'} c_{n,\sigma'} + h.c.) - a_y \sum_{n,\sigma,\sigma'} (c^\dagger_{n+1,\sigma}(i\sigma_z)_{\sigma,\sigma'} c_{n,\sigma'} + h.c.),$$

the RSO short range non-Hermitian AAH Hamiltonian is as,

$$H = H_{AA} + H_{RSO}.$$

- t and V_n $\rightarrow$ hopping amplitude and onsite potential respectively.
- p $\rightarrow$ shortrange parameter.
- c_n and $c^\dagger_n$ $\rightarrow$ fermionic annihilation and creation operators at site 'n'
- σ (or $\sigma\prime$) $\rightarrow$ for $\uparrow$ (or $\downarrow$) spin states.
- a_y & a_z $\rightarrow$ spin conserving and spin-flip RSO interaction strengths respectively.
- $\sigma_{x,y,z}$ $\rightarrow$ Pauli spin matrices .

The on-site quasiperiodic potential is given as,

$$V_n = V\ cos(2\pi\alpha n + ih).$$

- ih $\rightarrow$ complex phase, controlling the non-Hermiticity.
- α $\rightarrow$ golden ratio number $(\sqrt{5}+1)/2$.

NOTE: As we have considered Periodic Boundary Condition(PBC), so there is no skin effect.

Methods implemented

To determine the critical point, we estimate the Inverse Participation Ratio (IPR) and Normalized Participation Ratio (NPR),

$$\mathrm{IPR^{(i)}} = \frac{\sum_n |u^i_n|^4}{(\sum_n |u^i_n|^2)^2} \quad \text{and} \quad \mathrm{NPR^{(i)}} = \left[\mathrm{L}\sum_n |u^i_n|^4\right]^{-1},$$

- finite IPR value (tends to 1) indicate localized/insulating states or otherwise its delocalized/metallic states.
- as NPR is just inverse of IPR so reverse situation obseved in NPR case.
- DL transition is accompanied by $\mathcal{PT}$ symmetric breaking point.

Result and Discussion

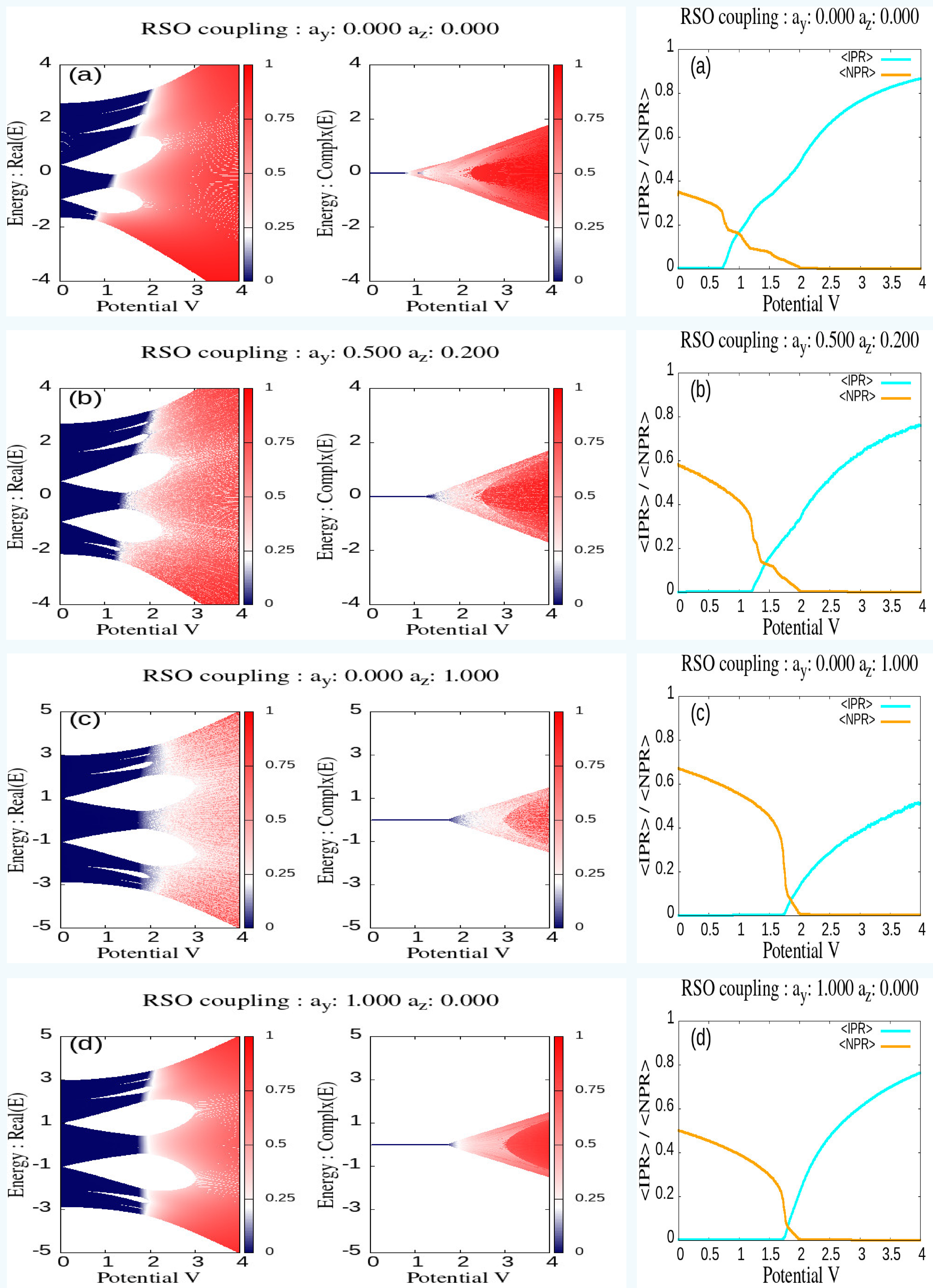

Figure: The energy eigenvalues of RSO non-Hermitian along with the IPR values for a system with lattice sites L=610, $\alpha = (\sqrt{5}+1)/2$, p=1.5 and h=0.5, under the PBC with different RSO coupling interaction strengths (a) $a_y = 0$ and $a_z = 0$ (b) $a_y = 0.5$ and $a_z = 0.2$ (c) $a_y = 0$ and $a_z = 1$ (d) $a_y = 1$ and $a_z = 0$. Here, t is taken as 1.

- Expected mobility edge without RSO (i.e: a_y and a_z are zero) $cosh(p) = \frac{Re(E)+t}{Ve^{|h|}}$
- Higher value of RSO strength (i.e: $a_y = 1$ or $a_z = 1$) reduce the mobility edge to almost sharp transition.

Conclusion

- Increasing RSO coupling value leads to reduce the mobility edge.
- It behave similar to the original AAH Hamiltonian with increasing the long-range parameter p.
- RSO coupling do not affect the qualitative behaviour of the $\mathcal{PT}$-symmetry.

References

[1] P. W. Anderson,Phys. Rev. 109, 1492–1505 (1958).
[2] S. Aubry and G. André, G. Srivastava, Ann. Israel Phys.Soc 3, 170403 (1980).
[3] J. Biddle, D. J. Priour, B. Wang, and S. Das Sarma,Phys. Rev. B 83, 075105 (2011).
[4] X. Deng, S. Ray, S. Sinha, G. V. Shlyapnikov, and L. Santos,Phys. Rev. Lett. 123, 025301 (2019).
[5] Y. Liu, X.-P. Jiang, J. Cao, and S. Chen,Phys. Rev. B 101, 174205 (2020).
[6] A. P. Acharya, A. Chakrabarty, D. K. Sahu, and S. Datta, Phys. Rev. B 105, 014202 (2022).

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