

Interchain coupling induced localization/delocalization in coupled one-dimensional ordered and disordered chains

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A different type of system with coupled ordered-disordered chains has given rise to considerable interest recently, as it has a variety of applications in nanostructures and biological systems such as DNA molecules. We investigate the localization/delocalization of coupled one-dimensional systems composed of one disordered chain (chain I) and another ordered chain (chain II), focusing on the interplay among the disorder, correlation, and interchain coupling. We find that for systems where chain I exhibits uncorrelated disorder, charge transport in chain I (II) is enhanced (suppressed), as the disorder in chain I leads to the localization of all states in both chains. However, for chain I with hopping amplitude t_1 and long-range *correlated disorder* (with power-law spectral density and disorder strength W), we find there is a localization/delocalization transition for the case $W \leq 4t_1$, induced by interchain coupling. For $W > 4t_1$, we find there is a quantum-phase transition at finite interchain coupling V_c : The interchain coupling induces appearance of two channels of extended states for $V > V_c$ while there is only one channel of extended states for $V < V_c$.

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I. INTRODUCTION

There are numerous studies in condensed-matter systems where the degree and type of disorder determine the character of electronic transport with drastically different properties possible. Ordered systems with spatial periodicity have continuous (dense) electronic spectra with spatially extended states due to Bloch's theorem. In contrast, disordered systems have, in general, discrete spectra with spatially localized states (especially for low-dimensional systems with uncorrelated disorder). The ability to create experimental systems with complex structures gives rise to the question: what are the properties of a system with coupled ordered and disordered components? This question is indeed not only of academic interest but has also direct applications in many real systems. Zhong and Stocks¹ investigated the transport properties of a surface-doped nanowire, considering the effects from the ordered core, as well as the disordered surface due to doping. Another important application is in modeling charge transport in DNA molecules.^{2–5} DNA molecules are composed of sugar-phosphate backbone chains, holding the genetically important sequence of nucleotide base pairs. The backbone has extended states due to its periodic structure.⁶ On the other hand, the sequence of base pairs in different DNA molecules, although nominally disordered, may reach different regimes (especially in artificially synthesized sequences), resulting in uncorrelated or correlated disorder.^{2,3,7–10} Recent studies^{4,5,11–17} on one-dimensional (1D) or coupled 1D systems show that the existence of correlation in disordered systems results in interesting properties with possibly quite different behavior, when compared with uncorrelated disordered systems.^{18–22} For instance, there are discrete extended states for 1D short-range correlated disordered systems,^{11–13} and even continuous bands of extended

states for long-range correlated disordered systems,^{4,14,17} in contrast to the absence of any extended states for 1D systems with uncorrelated disorder.²¹ It is therefore interesting and important to study the behavior in coupled ordered and correlated/uncorrelated disordered systems, and study the interplay of the different components (disordered chain I and ordered chain II) of the structure. In this paper, we explore the properties of two 1D coupled chains, where one is assumed to be disordered (chain I), while the other one is ordered (chain II), and will focus on the interplay among order/disorder and correlation, as the interchain coupling is changed. To this end, we study two complementary models. In model A, chain I exhibits uncorrelated disorder; in model B, chain I exhibits long-range correlated disorder.

We carry out both analytical and numerical calculations, and find that for model A, the ordered chain can always *enhance* particle transport in the disordered chain, even as the disordered chain *reduces* particle transport in the ordered chain. In model B, the situation is different. The ordered (disordered) chain can either assist (reduce) or suppress (enhance) the particle transport in the disordered (ordered) chain, depending on the various parameter regimes. Furthermore, as the interchain coupling is varied, we find that a quantum-phase transition is produced at a critical value of the interchain coupling.

The rest of the paper is organized as follows: in Sec. II, we construct our theoretical model and present an analytical analysis as well as a numerical approach based on the transfer-matrix method. The results and discussions are given in Sec. III. The paper ends with a brief summary and discussion section.

II. THEORETICAL MODEL

Our starting point is the following Hamiltonian for the double chain tight-binding model:

$$\begin{aligned}
H &= H_1 + H_2 + H_{21} + H_{12} \\
&= \sum_j [\varepsilon_{1,j} c_{1,j}^\dagger c_{1,j} + t_1 (c_{1,j}^\dagger c_{1,j+1} + c_{1,j+1}^\dagger c_{1,j})] \\
&\quad + \sum_j [\varepsilon_{2,j} c_{2,j}^\dagger c_{2,j} + t_2 (c_{2,j}^\dagger c_{2,j+1} + c_{2,j+1}^\dagger c_{2,j})] \\
&\quad + \sum_j V c_{2,j}^\dagger c_{1,j} + \sum_j V c_{1,j}^\dagger c_{2,j},
\end{aligned} \quad (1)$$

where $c_{s,j}$ is the annihilation operator for a particle at site j in chain I ($s=1$) or II ($s=2$), t_s is the corresponding nearest-neighbor hopping constant in each chain. H_1 describes a *disordered* chain with random on-site energy $\varepsilon_{1,j}$ distributed in the interval $[-\frac{W}{2}, \frac{W}{2}]$. H_2 describes an *ordered* chain with on-site energy ε_2 . V is the interchain coupling constant, which connects the chains “vertically” (via only the same site in each chain). We consider two different types of diagonal disorder distribution: for model A, the distribution is uniform; while for model B, the distribution function has a power-law spectral density, $S(k) \sim k^{-\alpha}$. As W defines the width of the distribution, it describes the strength of disorder, while α describes the degree of correlation. Methods for generating long-range correlated random on-site energies can be found in the literature.^{23,24}

To understand the impact of the disordered chain on the ordered chain, or vice versa, we use a Schrieffer-Wolff transformation to obtain the effective Hamiltonian for each chain: $H_{1,\text{eff}} = H_1 + H'_1$ and $H_{2,\text{eff}} = H_2 + H'_2$, where

$$H'_1 = H_{12}(E - H_2)^{-1}H_{21}, \quad (2)$$

$$H'_2 = H_{21}(E - H_1)^{-1}H_{12}. \quad (3)$$

First we perform a perturbative analysis. For small t_1 and V , we obtain the renormalization of on-site energies and hopping constants, due to interchain coupling, for chain II as

$$\delta\varepsilon_{2,j} = \frac{V^2}{E - \varepsilon_{1,j}}, \quad \delta t_{2,(j,j+1)} = \frac{V^2 t_1}{(E - \varepsilon_{1,j})(E - \varepsilon_{1,j+1})}. \quad (4)$$

Thus coupling to the disordered chain I brings about a certain degree of diagonal and off-diagonal disorder in chain II. As a consequence, localization may appear in chain II. Similarly, for small t_2 and V , the coupling to chain II leads to the renormalization of on-site energy and hopping constants for chain I as

$$\delta\varepsilon_{1,j} = \frac{V^2}{E - \varepsilon_2}, \quad \delta t_{1,(j,j+1)} = \frac{V^2 t_2}{(E - \varepsilon_2)^2}. \quad (5)$$

In the case of weak interchain coupling V , H'_1 has the form

$$H'_1 = \sum_{j,m} \beta_m c_{1,j}^\dagger c_{1,j+m} + \text{H.c.}, \quad (6)$$

where

$$\beta_m = \sum_k \frac{V^2 e^{ikm}}{E - \varepsilon_2(k)} = \frac{V^2}{2t_2} \frac{\rho_1^m}{\rho_1 - \rho_2} \quad (7)$$

with $\varepsilon_2(k) = \varepsilon_2 + 2t_2 \cos(k)$, $\rho_{1,2}$ the two roots of the equation

$$z^2 - 2zx + 1 = 0, \quad (8)$$

where $x = (E - \varepsilon_2)/2t_2$ and $\rho_1 = x - \sqrt{x^2 - 1}$ lies within the unit circle when $|x| > 1$. In this case β_m decays exponentially with a characteristic length $\lambda = \frac{1}{\ln(1/\rho_1)}$. When ε_2 approaches the energy levels of chain I, λ diverges, indicating a dramatic enhancement of charge transport in chain I. It is easy to check that β_0, β_1 reduce to $\delta\varepsilon_{1,j}, \delta t_{1,(j,j+1)}$, respectively, in Eq. (5) for small t_2 . The coupling to the ordered chain II results in the renormalization of the hopping between the nearby site in chain I. More importantly, this interchain coupling generates hopping to sites beyond the nearest neighbors, which is absent in the original Hamiltonian for chain I. Thus, it is natural to expect that chain II may enhance the charge transport in chain I. Basically, in the weak interchain coupling regime, the transport in chain I gets enhanced due to some mixing of states in chain I with extended states in chain II.

The analytical perturbative analysis above can give us an intuitive picture of the interplay between ordered and disordered chains as well as the possible consequences on particle transport properties. A quantitative nonperturbative calculation is needed for a better and more accurate assessment and understanding of the transport behavior. We use the transfer matrix method. From Eq. (1), the eigenstates can be found by solving the following equations:

$$\varepsilon_{1,n} \alpha_{1,n} + t_1 (\alpha_{1,n+1} + \alpha_{1,n-1}) + V \alpha_{2,n} = E \alpha_{1,n},$$

$$\varepsilon_2 \alpha_{2,n} + t_2 (\alpha_{2,n+1} + \alpha_{2,n-1}) + V \alpha_{1,n} = E \alpha_{2,n}, \quad (9)$$

where $\alpha_{1,n}$ ($\alpha_{2,n}$) is the probability amplitude for a particle at site n in chain I (chain II). Equation (9) can be written in matrix form^{5,16}

$$\Phi_{n+1} = \begin{pmatrix} \alpha_{1,n+1} \\ \alpha_{2,n+1} \\ \alpha_{1,n} \\ \alpha_{2,n} \end{pmatrix} = T_n \begin{pmatrix} \alpha_{1,n} \\ \alpha_{2,n} \\ \alpha_{1,n-1} \\ \alpha_{2,n-1} \end{pmatrix} = T_n \Phi_n, \quad (10)$$

where

$$T_n = \begin{pmatrix} \frac{E - \varepsilon_n}{t_1} & -\frac{V}{t_1} & -1 & 0 \\ -\frac{V}{t_2} & \frac{E - \varepsilon_2}{t_2} & 0 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix}. \quad (11)$$

Then we have $\Phi_N = \hat{T}_N \Phi_1$, where $\hat{T}_N = \prod_{i=1}^{N-1} T_i$. The localization length λ at energy E is the inverse of the Lyapunov coefficient ($\gamma > 0$), which is the smallest positive eigenvalue of the limiting matrix $\lim_{N \rightarrow \infty} \ln(\hat{T}_N \hat{T}_N^\dagger)^{1/2N}$.²⁰ The normalized localization length $\Lambda = \lambda/N$ is used in the following to describe the degree of localization. In the calculations, the reorthogonalization method²⁵ has also been used and we have performed averages over 400 disordered configurations. In the following, we explore detailed results for different disorder and interchain couplings.

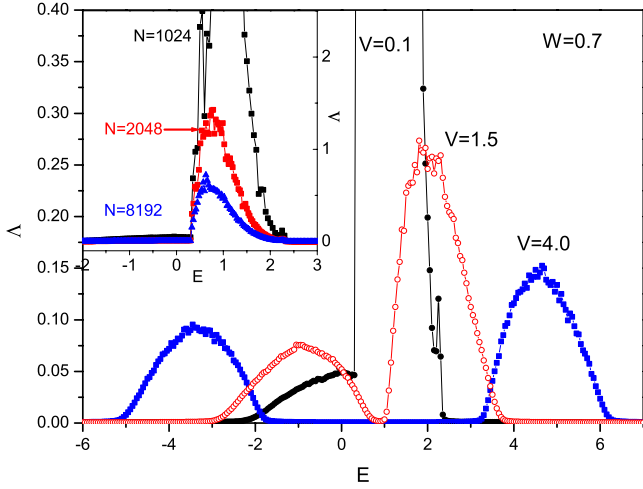


FIG. 1. (Color online) Normalized localization length Λ for different interchain coupling V . Chain I is described by the Anderson model with intrachain hopping $t_1=1$ and the on-site energy distributed uniformly in the interval $[-\frac{W}{2}, \frac{W}{2}]$ with $W=0.7$. Chain II is fully ordered with intrachain hopping $t_2=0.5$ and on-site energy $\varepsilon_2=1.3$. The size of each chain is $N=1024$. Inset: normalized localization length Λ for different chain lengths, all with interchain coupling $V=0.1$.

III. RESULTS AND DISCUSSIONS

A. Model A: Uncorrelated disordered chain

We first consider the model A with uncorrelated disorder in chain I. Figure 1 shows the normalized localization length $\Lambda=\lambda/N$ versus energy E for model A. It is clear that for small ε_2 and V , there is partial overlap between the spectra of the two chains, and the mixing of the corresponding states leads to drastic enhancement of the localization length for the original localized states, whenever the two chains overlap (are in resonance). For large V , however, the energy-level repulsion effect from the interchain coupling is large, eliminating the energy overlap and producing strong suppression of the localization length in the system. We see then that the interchain coupling has dual roles: (i) it causes level repulsion between energy levels in the two chains and (ii) it mixes the states of the two chains, leading to the enhancement of the localization length of states in chain I and suppression of the localization length of states in chain II. [Notice that there is some mixing between states in both chains so that a complete description should involve states of the two chains in the coupled system. Usually interchain coupling leads to the formation of two channels (channels I and II). In the case of weak interchain coupling, the states in channel I/II are states in chain I/II with small mixing of states from chain II/I, and the different weights in the wave function preferentially label each state as coming from chain I or II.] One can then say that the interchain coupling increases (decreases) the degree of wave-function extension of chain I (II). Here we would like to point out that all states are localized in the thermodynamic limit, i.e., $\Lambda \rightarrow 0$ as the system's size $N \rightarrow \infty$, as shown explicitly in the inset of Fig. 1. The one-parameter scaling theory points out that *all* eigenstates are localized in 1D and two-dimensional uncorrelated disordered systems.²¹ It is un-

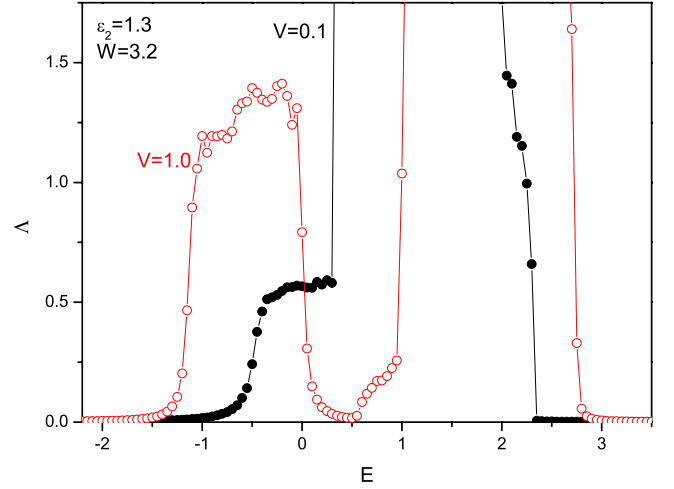


FIG. 2. (Color online) Normalized localization length Λ for different interchain coupling V . Chain I is described by a long-range correlated disorder model with intrachain hopping $t_1=1$ and on-site energy distributed in the interval $[-\frac{W}{2}, \frac{W}{2}]$, with $W=3.2$, and with power-law correlation function $\sim k^{-\alpha}$, and $\alpha=2.5$. Chain II is described by an ordered model with intrachain hopping $t_2=0.5$ and on-site energy $\varepsilon_2=1.3$. The size for each chain is $N=1024$.

derstandable that all eigenstates of the coupled disordered-ordered two chains (essentially a 1D disordered system) will be localized in the thermodynamic limit.

B. Model B: Long-range correlated disordered chain

There have been many studies on the properties of disordered systems with long-range correlations.^{14,15,17,23,24} It has been found that there exists a continuous band of extended states under suitable conditions and some of the theoretical predictions have been verified in experiments.²⁶ Moreover, recent developments and the tunability of properties in cold atom systems provide new opportunities for investigating various aspects of correlated disordered systems.²⁷ We first recall some basic results for long-range correlated disordered chains relevant for our current studies. More details can be found in a recent paper from our group.²⁴ We find that there are mobility edges at $E_c = \pm |2t_1 - W/2|$ for $\alpha > 2$ and $W < 4t_1$. In this case there exists an effective band of extended states with bandwidth $4t_1 - W$. This suggests that one can view chain I as an effectively ordered system with a smaller effective hopping $\bar{t}_1 = t_1 - W/4$ in a tight-binding model.

1. Regime I: $W \leq 4t_1$

We first consider the regime with $W \leq 4t_1$, in which the chain I has an effective band (with width $4t_1 - W$) of extended states in the absence of interchain couplings.²⁴ We show the normalized localization length versus energy for model B with small ε_2 in Fig. 2, which shares some features with Fig. 1. There is a mixture of states for two chains for small V while the two channels separate for larger V due to energy-level repulsion. One important point of difference is that these are *true* extended states. (Here and in the following we have checked with finite-size scaling²⁴ that the “extended

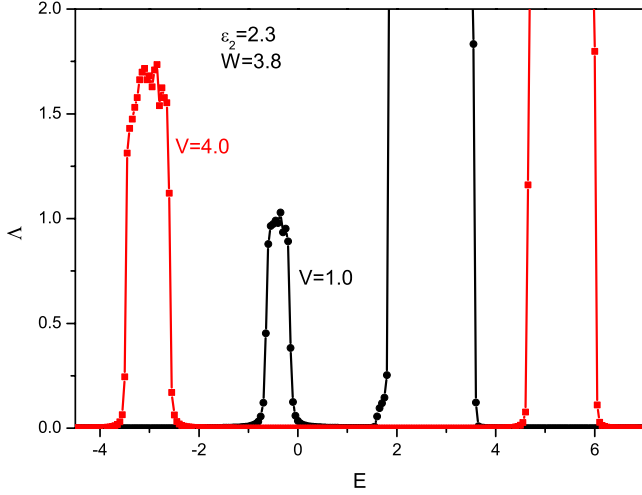


FIG. 3. (Color online) Normalized localization length Λ for different interchain coupling V for larger $\varepsilon_2=2.3$ and $W=3.8$. All other parameters are the same as in Fig. 2.

states” are truly extended even in the thermodynamic limit.) From the discussions in Sec. II, one knows that although the interchain coupling introduces disorder in chain II, there are still extended states due to the presence of correlation in chain I. It is also interesting to notice the asymmetry in Λ versus energy. As the energy approaches the ordered chain sequence ($E \approx \varepsilon_2$), Λ increases dramatically.

Figures 3 and 4 show the normalized localization length versus energy for model B in the regime of large ε_2 , where the two channels totally separate. Figure 3 shows the dependence on interchain coupling V while Fig. 4 shows the dependence on the strength of disorder W . First, due to the existence of correlation in the disordered chain I, there is still a continuous band of extended states in channel I. The (effective) bandwidth (for the band of extended states with infinite localization length in the thermodynamic limit) is ob-

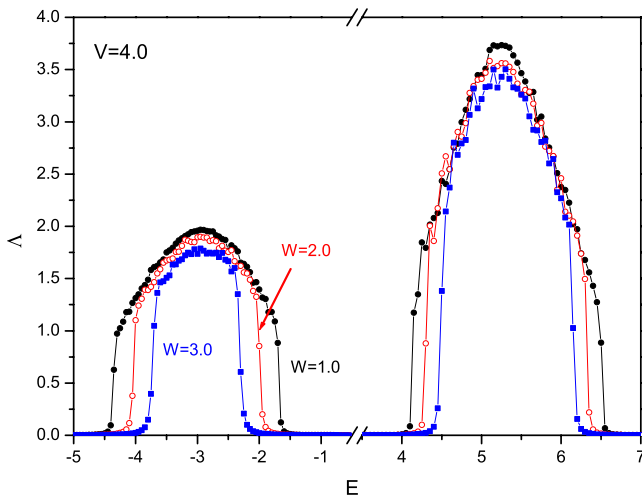


FIG. 4. (Color online) Normalized localization length Λ for coupled ordered chain II and long-range correlated disordered chain I. Interchain coupling is $V=4.0$ while the disorder strength for chain I is $W=1.0, 2.0$, and 3.0 for each curve, as indicated. All other parameters are the same as in Fig. 3.

tained by finite scaling analysis as described in Ref. 24. In general, it is found that the interchain coupling changes both the effective bandwidths of channels I and II: it makes the original wide/narrow band (without interchain coupling) effectively narrower/wider. A careful analysis of the bandwidth shows also that the total bandwidth (the addition of bandwidths for the two channels) remains constant as V varies, when the disorder strength W is kept fixed. Increasing W leads to an overall reduction of the total bandwidth. With this in mind, the numerical results above can be understood in the following way.

Chain I may be viewed as an effective ordered system with effective hopping $\bar{t}_1 = t_1 - W/4$. Then we consider the equivalent system of two coupled ordered chains. The on-site energy and hopping constant are $\varepsilon_1=0, \bar{t}_1$ for chain I and ε_2, t_2 for chain II. The eigenenergy for the equivalent system can be obtained as

$$\begin{aligned} \varepsilon(k) = & \frac{1}{2}(\varepsilon_1 + \varepsilon_2 + 2\bar{t}_1 \cos k + 2t_2 \cos k) \\ & \pm \frac{1}{2}\sqrt{4V^2 + (\varepsilon_2 - \varepsilon_1 + 2t_2 \cos k - 2\bar{t}_1 \cos k)^2}. \end{aligned} \quad (12)$$

For large $|\varepsilon_1 - \varepsilon_2|$, there are two bands with bandwidths

$$\begin{aligned} B_1 &= \frac{1}{2}|4\bar{t}_1 + 4t_2 + \Delta_1 - \Delta_2|, \\ B_2 &= \frac{1}{2}|4\bar{t}_1 + 4t_2 - \Delta_1 + \Delta_2|, \end{aligned} \quad (13)$$

where

$$\begin{aligned} \Delta_1 &= \sqrt{(\varepsilon_1 - \varepsilon_2 + 2\bar{t}_1 - 2t_2)^2 + 4V^2}, \\ \Delta_2 &= \sqrt{(\varepsilon_1 - \varepsilon_2 - 2\bar{t}_1 + 2t_2)^2 + 4V^2}. \end{aligned} \quad (14)$$

For small V and large $|\varepsilon_1 - \varepsilon_2|$

$$B_1 = 4\bar{t}_1 + V^2 \frac{t_2 - \bar{t}_1}{(\varepsilon_1 - \varepsilon_2 - 2\bar{t}_1 + 2t_2)(\varepsilon_1 - \varepsilon_2 + 2\bar{t}_1 - 2t_2)}. \quad (15)$$

It is clear that the effective bandwidth B_1 for channel I increases when $t_2 > \bar{t}_1$ and decreases when $t_2 < \bar{t}_1$. The enhancement is proportional to V^2 . The bandwidth remains invariant when $\bar{t}_1 = t_2$, as also seen in Fig. 4. [For the parameters used in Fig. 4 ($t_1=1, t_2=0.5, W=2.0, V=4.0$), the effective hopping constant $\bar{t}_1 (=t_1 - W/4=0.5)=t_2$. Figure 4 shows that the bandwidth of channel I of coupled system (with $V=4.0$) is 2.0, which is equal to the effective bandwidth for chain I in the absence of interchain coupling ($V=0$) $4t_1 - W=2.0$. This numerical result agrees very well with the prediction based on Eq. (15).] From Eq. (13), it is clear that the total bandwidth $B_1 + B_2$ remains constant for fixed W , as observed in our numerical results. It is interesting to see that the interchain coupling may also enhance (reduce) the bandwidth of the ordered chain II (disordered chain I) as seen in Fig. 4.

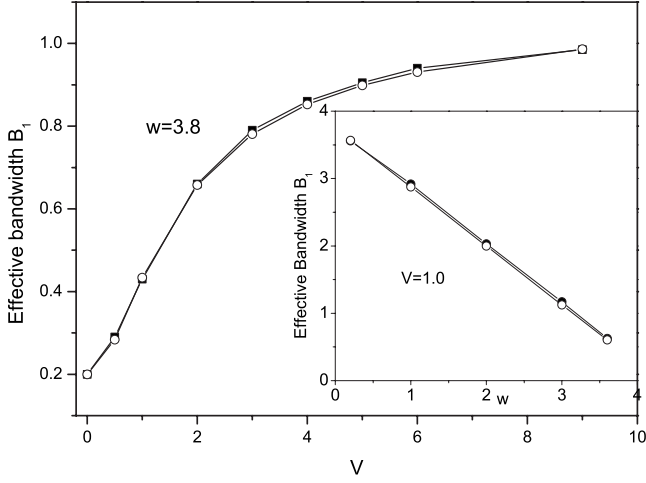


FIG. 5. Effective bandwidth of channel I versus V (with $W=3.8$). Inset: effective bandwidth of channel I versus W (with $V=1.0$). All the parameters except V and W are the same as in Fig. 3. The curves with solid squares are for numerical results with white circles are for analytical results from Eqs. (13) and (14).

There is excellent agreement between analytical and numerical results, as shown in Fig. 5, where it is shown that the effective bandwidth for channel I increases with increasing interchain coupling V or decreasing disorder strength W . From Eq. (12), one can also find the correction to the energy $E = \varepsilon_1 + 2\bar{t}_1 \cos k$

$$\Delta\varepsilon = \frac{V^2}{E - \varepsilon_2 - 2t_2 \cos k} \sim \frac{V^2}{E - \varepsilon_2} + \frac{V^2}{(E - \varepsilon_2)^2} 2t_2 \cos k \quad (16)$$

for small V and t_2 . This is just the renormalization of on-site energy and hopping constant for chain I we found in Eq. (5).

2. Regime II: $W > 4t_1$

In this situation, $W > 4t_1$, all eigenstates of chain I in the absence of interchain coupling are localized.²⁴ Considering the results of Sec. III A, one may suspect that all eigenstates are then localized. It turns out this is *not* the case. In the inserts of Fig. 6 we show the normalized localization length versus energy for $W=4.5$ and $V=0.5, 3.0$. For small interchain coupling ($V=0.5$), there exists a band of extended states in channel II even in the thermodynamic limit, (in spite of the coupling to the localized states in the strongly disordered chain I) unlike the case in Sec. III A. Interestingly, larger interchain coupling ($V=3$) has even bigger impact on channel I, as the ordered chain II generates a narrow band of extended states in channel I. This effect is the interchain coupling induced delocalization. The main panel in Fig. 6 is the total bandwidth versus V . We find a critical interchain coupling $V_c \approx 1.45$ such that for small $V < V_c$, there are only extended states in channel II and all states in channel I are still localized. The total bandwidth decreases with increasing V . However, for strong interchain coupling $V > V_c$, there are extended states in both channels. With increasing V , the bandwidth of channel I/II changes, but the total bandwidth

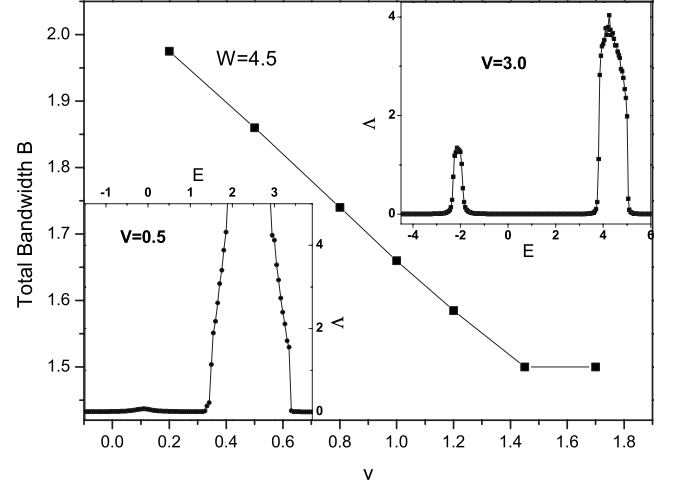


FIG. 6. Total bandwidth versus interchain coupling V for $W=4.5$ and $\varepsilon_2=2.3$; hopping parameters $t_1=1.0$ and $t_2=0.5$. Right (left) inset: normalized localization length versus energy for $V=3.0$ (0.5).

$= 4t_1 - W + 4t_2$ remains constant. For large V and $W=4.5$, one could consider chain I with bandwidth $4t_1 - W = -0.5$ is coupled to chain II with bandwidth 2 so that the system has a total bandwidth $-0.5 + 2 = 1.5$. This can be understood, when V is large, by mapping the original problem to a system of two chains with on-site energy $\varepsilon_{\text{eff}} = (\varepsilon_{1,n} + \varepsilon_2)/2 \pm V \in [\pm V - W/4, \pm V + W/4]$, and hopping constant $t_{\text{eff}} = (t_1 + t_2)/2$. Then the total bandwidth is $2(4t_{\text{eff}} - W/2) = 4t_1 + 4t_2 - W = 1.5$ for $t_1=1, t_2=0.5$, and $W=4.5$. Therefore for $W > 4t_1$, we find two phases: phase (a) for small interchain coupling $V \leq V_c$, in which all states in channel I are localized and the total bandwidth decreases with increasing V ; phase (b) for larger interchain coupling $V > V_c$, in which the interchain coupling induces delocalization in channel I and the total bandwidth remains a constant.

The dependence of the total bandwidth on W also shows different behavior for weak and strong interchain coupling. We display the dependence of total bandwidth for $V=1.0$ and 9.0 in Fig. 7. For weak interchain coupling and weak disorder, there are extended states in channel I and channel II, and total bandwidth B has a linear dependence on W , as shown in last section for $W < 4t_1$. For $W > 4t_1$, the extended states in channel I disappear and there is a weaker dependence of B on W . There are extended states for $W > 4t_1 + 4t_2$ due to the weaker impact of the disordered chain I in the case of weak interchain coupling. When W is larger than a critical value (~ 10), all states are localized. For large $V=9$ and $W < 4t_1$, the dependence of the total bandwidth is the same as for small V . The picture is very different for strong interchain coupling and $W > 4t_1$. There, the total bandwidth maintains a linear dependence on W as described by $4t_1 + 4t_2 - W$. For larger disorder, the total bandwidth vanishes and all the states are localized. (The system may show different behavior as W increases further to much larger values; see Fig. 8 and related discussions.) These results show the importance of correlation in the disorder, as the nature of the states in that regime

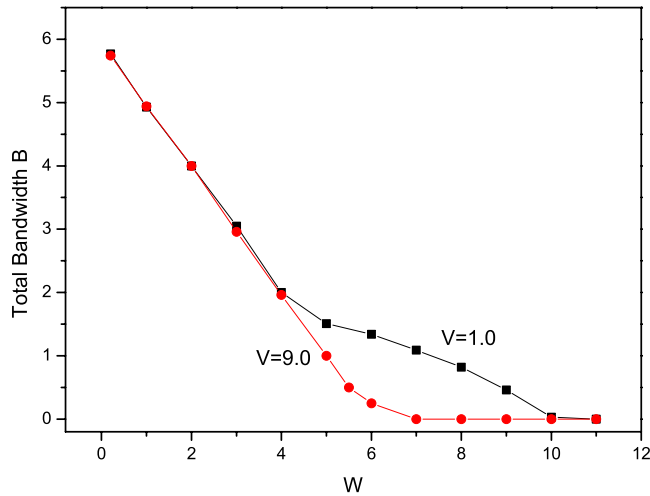


FIG. 7. (Color online) Total bandwidth versus strength of disorder W . The (black) curve with squares is for $V=1.0$ and the (red) curve with circles is for $V=9.0$. Other parameters as in Fig. 6.

are intrinsically different than in uncorrelated disorder systems. Unlike the localized states in uncorrelated disorder systems, the original localized states of the uncoupled correlated disordered chain I only lead to localization of *part* of the states in chain II for the case with weak interchain coupling. This weaker localization effect (compared with the case with uncorrelated disorder) of chain I on chain II is indeed due to the correlation in chain I. Moreover, strong interchain coupling may even delocalize some of the original localized states in chain I. The appearance of extended states in channel I is the combined effect of the strong interchain coupling and the intrinsic correlation in chain I. The correlations in the disordered chain I ensure the existence of a quantum delocalization transition with increasing interchain coupling.

Figure 8 shows the dependence of Λ versus W in the very strong disorder regime. One can see that the dependence is not monotonic. With increasing W , Λ first decreases, and then increases for *very* large W . This unusual dependence on W is due to the fact that most states in chain I decouple from the states in chain II because of their large energy difference.¹

IV. CONCLUSION

We have investigated the properties of a 1D uncorrelated/correlated disordered chain (chain I) coupled to an ordered chain (chain II). We find that this hybrid complex system may exhibit various different behaviors depending on the interplay among disorder, correlation, and coupling strength. For coupled uncorrelated disordered and ordered chains, the interchain coupling increases/decreases the extension of the wave function of the disordered/ordered chain. All states are localized due to the presence of disorder. For chain I with weak correlated disorder, i.e., $W < 4t_1$, the presence of correlation leads to the existence of a band of extended states for uncoupled chain I. The interchain coupling increases/

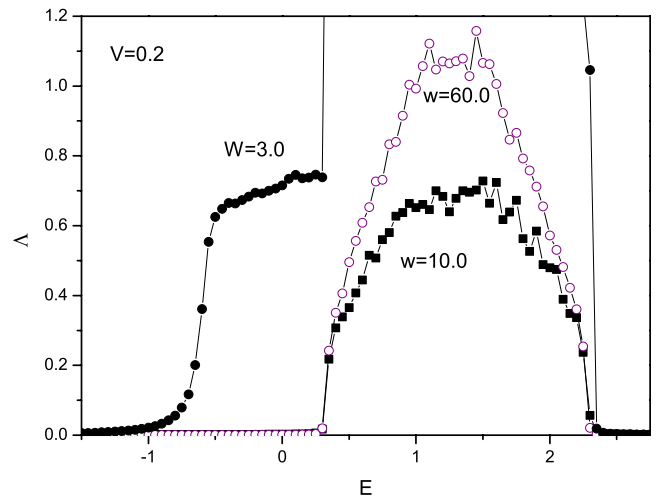


FIG. 8. (Color online) Normalized localization length versus energy for large disorder strength $W=3.0$, 10.0 , and 60.0 ; $V=0.2$. All other parameters are the same as in Fig. 2. Notice nonmonotonic dependence of Λ on W value.

decreases the (effective) bandwidth of the original chains with narrower/wider bandwidth (without interchain coupling) and keeps the total bandwidth constant. For strong disorder $W > 4t_1$, all states of uncoupled chain I are localized. These localized states in chain I show different properties compared with the localized states in chain I with uncorrelated disorder. For weak interchain coupling, these original localized states remain localized, and they lead to *part* of the extended states in (original) order chain II localized (which is quite different from the localization of *all* states in the first case with uncorrelated disorder in chain I). When the interchain coupling becomes larger than a critical value, part of the original localized states in channel I become delocalized due to the strong effect from ordered chain II and intrinsic correlation in chain I (the lack of correlation prevents the delocalization). Therefore we find a quantum delocalization transition of states in channel I as function of interchain coupling.

Although in some systems the disorder, correlations, and interchain couplings may be varied only over a narrow range, advances in technology and great innovation may allow experimentalists to explore the different regimes we have discussed. We trust that this work would motivate further work to probe the localized/delocalized nature of electronic states in different regimes.

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