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DELOCALIZED ELECTRONIC STATES IN 1D SUPERLATTICES WITH CORRELATED DISORDER

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ABSTRACT

Models of one-dimensional systems with short-range correlated disorder have predicted the existence of an energy region where the states are delocalized. This is in contrast to the earlier belief that all the eigenstates are localized in 1D disordered systems. We study the statistical properties of the spectrum of finite superlattice formed from short chains with correlated disorder (repulsive binary alloy).

In mesoscopic physics the effect of disorder on the electron propagation leads to the Anderson metal-insulator transition at $T = 0$ [1]. It is generally argued that, in the case of full randomness of parameters of the model, all states are localized in 1D systems [2]. This implies that there is no regime of diffusive (metallic) behavior. However, in recent years, a number of models [3, 4, 5] have predicted the existence of sets of extended states in an energy region, as a consequence of the introduction of short-range correlations. One of these is called repulsive binary alloy (RBA), in which the inhibition of bond between one of the atomic species introduces the above correlation [6]. We have presented in a previous work [7] a model of disordered quantum well (DQW) made from a short portion of RBA among ordered barriers. The system shows quantum effects due to spatial confinement, within the energy range where the well material presents these extended states. This is a consequence of the multiple constructive interference of the states, which localization lengths are at least three times longer than the well wide. An interesting question arises about the coupling of DQWs in finite superlattices (SLs). The aim of this paper is to present statistical properties of energy spectra in disordered one-dimensional finite SLs and relate it to the transport properties.

We show that the coupling of disordered quantum wells in SL can be described by appropriate nearest level spacing statistics for an ensemble of configurations [8]. Furthermore, the level spacing statistics evolve to Poisson or Wigner surmise distributions in finite SLs, as a function of the miniband position inside of delocalization window as the level position in their respective miniband.

The Hamiltonian corresponds to the an one-dimensional tight-binding chain of s-like orbitals,

$$H = \sum_n (\epsilon_n |n >< n| + V_{n,n+1} |n >< n+1| + V_{n+1,n} |n+1 >< n|) \tag{1}$$

The well material has 40 atomic sites long among ordered barriers of $L_b(2,3)$ sites for each ensemble. The hole chain is ended in both sides by wider barriers in order to minimize surface effects. The number of quantum wells in a finite SL

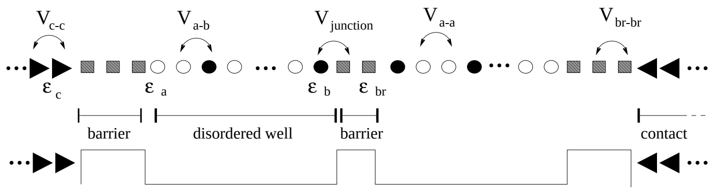

Figure 1: Model of disordered superlattice (SL)

varies in the range $2 \leq N_w \leq 16$, Fig 1. Tight-binding parameters are the same of reference [6]. Each well layer is characterized by the correlation used, i.e. in a chain of A and B sites the $B - B$ bond is forbidden, and the concentration of B-like sites (for this case $\rho_B \approx 0.3$). Disorder is introduced by randomly assigning A and B sites, according to the above constraints. The size of ensembles is 1000 configurations.

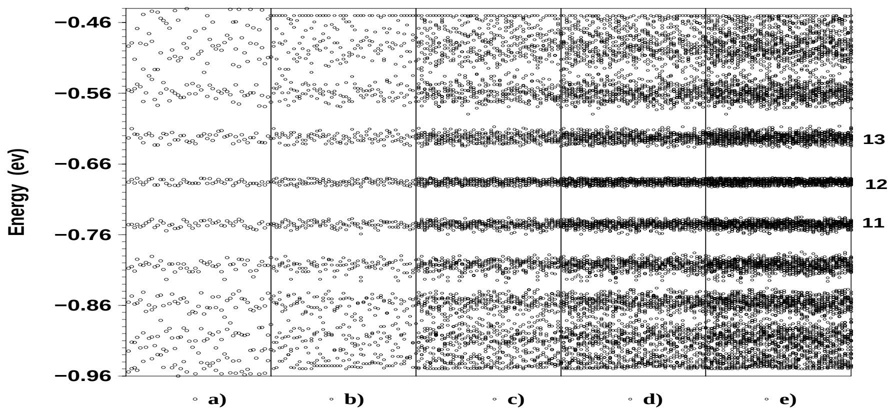

Figure 2: Energy spectra for 80 different disordered configurations: (a) one, (b) two, (c) six, (d) ten, and (e) sixteen five disordered quantum wells.

In Fig.2 we show the energy spectra as a function of ensemble configuration for different systems. Only the spectra in the range of an infinite RBA delocalization window is shown. According to the parameters and the well wide, the bona fide quantum well states correspond to the index $n = 11$, $n = 12$ and $n = 13$.

The energy spectrum of an ensemble of single DQWs with the same macroscopic characteristics shows fluctuations due to the disorder, which are strongly suppressed without total disappearance, in the delocalization window, Fig 2a). On the other hand, spatial overlap between electronic states of neighboring ordered quantum wells in finite SLs shifts the degenerate energy levels, and leads to the appearance of minibands separated by minigaps [9]. One state in these minibands arises from each well in the SL, and the distance between two consecutive levels

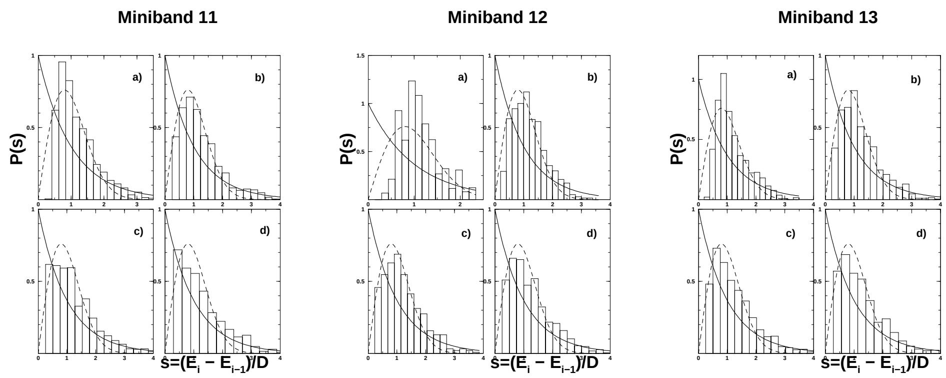

Figure 3: Nearest level spacing distribution for central levels in the 11, 12 and 13 minibands of: (a) two (b) six (c) ten and (d) sixteen quantum wells.

(*level spacing s*) is dependent on the overlap of the envelope functions, i.e. a level repulsion [10].

When it is considered only a system of two DQWs, inside the delocalization window, the spectrum of the ensemble shows level clusterings around the average energy of each single DQW level, Fig 2b). We call these clusters minibands of the disordered system. However, if these show signatures of a true miniband, like in ordered systems, will depend on if it's possible to determine a nearest neighbor level spacing, which source will be in a level repulsion by coupling of the same, no matter the fluctuations due to disorder. As we can see it is impossible resolve qualitatively from the spectra some level repulsion due to the relatively large level fluctuations. Then, the existence or not of coupling between DQWs can be only verified by the level spacing distribution. Nearest neighbor level spacing distribution for the most central levels of the minibands $n = 11$, $n = 12$ and $n = 13$ with $l_b = 2$ are shown in Fig.3. The numerical histograms are compared to analytical Poisson and Wigner distributions for the numerical average level spacing, D, calculating the Chi square distance, Table 1. Only, the systems of two and six DQWs show a clear approaching to Wigner distribution for $n = 12$ miniband, which is expected for correlated levels. This character is not well define in the $n = 11$ and $n = 13$ of two DQWs. These two minibans approaches to Poisson for six DQWs, which is expected for uncorrelated states. Systems more larger already show a clear approaching to Poisson distribution for all minibands in the delocalization window, i.e. all states are localized. By increasing the barrier thickness, $l_b = 3$, the statistics approaches a Poisson distribution indicating a strong suppression of the overlapping of the well states (results not shown). On the other hand, all nearest level spacing distributions for the levels at the edges of minibands have tendency towards localization.

In conclusion, we have shown that minibands of disordered finite superlattices can be characterized by a statistics on the nearest neighbor level spacing. This is

Miniband 11				
Histograma	a)	b)	c)	d)
χ^2 Wigner	335.3	32529.8	106515	1.7×10^9
χ^2 Poisson	368.7	144.9	87.5	42.1
Miniband 11				
Miniband 12				
χ^2 Wigner	206.2	48.3	539.1	13087.4
χ^2 Poisson	874.2	325.4	175.9	102.1
Miniband 13				
χ^2 Wigner	158.9	419.6	15768.5	8.6×10^6
χ^2 Poisson	435.7	192.4	110.7	76.4

Table 1: Chi square distance of the histograms to Wigner surmise and Poisson distribution

necessary because the fluctuations due to disorder screening a level spacing due to the repulsion between well states levels. Only small systems made from the joining of DQWs show signatures of true minibands. And this is restricted to the most central states in the miniband which energy is related to the maximum localization length of an infinite RBA [7].

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