

We investigate a formation of electron strings due to short and long-range electron-phonon and electron-electron interactions.

PACS numbers: 71.10, 61.82.Fk, 61.82.Bg, 71.45.Gm

There is a growing body of experimental evidences[?, ?, ?, ?] and theoretical arguments[?, ?] indicating on existence of stripe structure. The stripe structure has been also observed in other oxides, manganites[?], where the important role of the lattice effect is observed. Independently from these experiments, we have recently suggested that the lattice plays an important role in a self-trapping of electrons in the form of a long cigar shaped object named as *strings*. The string's phenomenon is a many-particle generalization of the self-trapping of a single electron. In the present work we have extended our studies, taking into account the finite bandwidth and treat the kinetic energy of the string. In general such strings may correspond to either a ground state or a metastable state. For a short range electron-phonon interaction. However in the present paper we limit ourselves by studies of a single highly conducting string.

We have employed the Hartree-Fock many body-wave function as a variational wave function to describe fermions self-trapped in a string. We consider the general Hamiltonian of spinless fermions interacting via a strong long-range electron-electron repulsion.

where t is the electron hopping-integral, the operator $a_i^\dagger(a_i)$ creates (destroys) a fermion at a lattice site i , n_i is the occupation number.

The function $\gamma(q)$ and the phonon dispersion relation $\omega(q)$ are different for different types of the electron-phonon interaction.

where it is plausible to assume that for spinless fermions the effective dielectric constant $\bar{\epsilon}$ may be taken as $\bar{\epsilon} = \epsilon_\infty$. Such Hamiltonian

The Hartree-Fock many-body wave function of the M self-trapped particles $\Psi(1, 2, \dots, M)$

which we employ to calculate an expectation value of the Hamiltonian, eq.(??) has a form of a Slater determinant

consisting of single particle wave functions:

Each of these wave functions describes the electron(hole) trapped by N neighboring sites (string potential well) with equal probability.

where d is a dimension of the hypercubic lattice, the value n is an electron(hole) doping inside the string: $n = M/N$. For the case of a single electron string valid for a wide range of the parameters of the Hamiltonian such as a coupling constant c , the bandwidth W .

After the substitution of this expression into the eq.(??) for E_S we get the dependence $E_S = E_S(n)$ on the doping of the string.

The minimum energy E_S associated with an insulating string which has been calculated with the use of the relation $M = Nn$.

The comparison of eq.(??) and with the energy of M single polarons equal to $M(2dt - c/2)$ indicates that an insulating string is formed in a doped antiferromagnet. For a single hole in the antiferromagnet there is an increase in the exchange energy equal to $2c$.

where the value M is defined by eq.(??). The comparison of this expression with the total energy of M separated self-trapped electrons

Thus, the exchange interaction between anti-ferromagnetic spins significantly improves the physical conditions required for the formation of strings. All these string solutions found for deformational type of strings arise also in the case when the electron is interacting with phonons.

where λ is a constant of the Jahn-Teller electron-phonon coupling and c_{11} , c_{12} are conventional elastic modulus for a crystal. The string length depends on the type of the string and must be estimated by a minimization $E_S(n)$ with respect to the string length n . The case when a single electron or a hole is interacting with polar phonons, i.e. with longitudinal optical phonons with frequency ω_{LO} . Then the value of total energy including the Coulomb and exchange contributions from the long-range Coulomb forces

The value of the doping n may be calculated numerically after the next substitution of eq. (??) into eq.(??) and next mini to only one variable, n . In the limit when the string has a very low density $n \ll 1$ the values of M and N may be pres

The total energy of the string per electron equals $j_{string} = 2d - 2 + 2/N - nE_c$. To be in a ground state this string energy

which is roughly means that the polaron shift must be smaller than the string bandwidth $2t$.

Thus, we arrive at the conclusion that in oxide compounds having ionic character of the bonding the formation of high Our findings are probably relevant to stripe formation observed in HTSC [?, ?, ?, ?, ?, ?, ?, ?, ?] To check if this cri Thus, we arrive at the conclusions that in polar oxide materials, like HTSC there may arise electronic strings which ar which may be associated with the string's dynamics.

The observed stripes may be related to the hole strings arising for a small hole doping. Such strings may well form a V In summary, we found that in oxides HTSC there may arise *highly-conducting* electron strings which are linear electron

Acknowledgment

I am very grateful to S. Kivelson, D. Edwards, G. Gehring, V. Emery, E.I. Rashba, Danya Khomskii and Harj Dhillon H.A.Mook, Pengcheng Dai, F. Dogan, R.D. Hunt, Nature, **404** 729 (2000) R.P. Sharma et al, Nature, **404**, 736 (2000) A. Lanzara, G. Zhao, N. L. Saini, A. Bianconi, K. Conder, H. Keller and K. A. Müller, J. Phys. Cond. Matt. **11**, L541 (19 M.Uehara, S. Mori, C.H. Chen and S. W. Cheong, Nature,**399** 560 (1999) ... F.V. Kusmartsev, J. de Physique IV,**9**, Pr10-321, (1999) F.V. Kusmartsev, Phys.Rev.Lett. **84**, 530 (2000); Phys.Rev.Lett. **84**, 000 (2000) E.I. Rashba, in: Excitons, ed. by E.I.Rashba and M.D. Sturge, North-Holland (Amsterdam) 1982, p.543. E.L. Nagaev, Sov. Jour.- JETP Lett., **16**, 558 (1972); V.A. Kaschin and E.L. Nagaev, Zh. Eks. Teor. Fiz., **66**, 2105 (1974) J.R.Zaanen and O. Gunnarson, Phys. Rev. **B40**, 7391 (1989) U. Löw, V. J. Emery, K. Fabricius and S.A. Kivelson, Phys. Rev. Lett. **72**, 1918 (1994) V.J. Emery, and S.A. Kivelson, Nature (London) **374**, 434, (1995); V.J. Emery, S.A. Kivelson, and O. Zachar, Phys. Rev, I V.J. Emery, S. Kivelson and H.Q. Lin, Physica **B163**, 306, (1990); Phys. Rev. Lett. **64**, 475, (1990) A. Biancone, Phys. Rev. **B54**, 12018 (1996); M.v. Zimmermann et al, Eur.Phys. Lett. **41**, 629 (1998). T.R.Thursten et al, Phys. Rev. **B40**, 4585 (1989). J.M. Tranquada, Nature (London) **375**, 561, (1995). A. Bianconi et al, Phys. Rev. Lett. **76**, 3412 (1996); and see references therein. (1995); H.A. Mook, P. C . Dai, S.M. Hayden, G. Aeppli, T. G. Perring and F. Dogan, Nature, **395** 580 (1998) N.L.Saini, J.Avila, A.Bianconi, A.Lanzara, M.C.Asensio, S.Tajima, G.D.Gu and N.Koshizuka, Phys. Rev. Lett. **79**, 3467 (S.I. Pekar, Untersuchungen über die Elektronentheorie Kristalle, Akademie Verlag, Berlin, 1954. A.S. Alexandrov and V.V. Kabanov (unpublished) L.P.Gorkov and A.B.Sokol, Pisma Zh. Eksp. Teor. Fiz. **46**, 333 (1987) F.V.Kusmartsev, unpublished V.J. Emery, S.A. Kivelson and J.M. Tranquada, Proc. Natl. Acad. Sci. USA **96** 8814 (1999) * On a leave from Department of Physics, Loughborough University, LE11 3TU, UK