ISSN (Print) 1226-1750
ISSN (Online) 2233-6656
Journal of Magnetics 19(2), 140-145 (2014) http://dx.doi.org/10.4283/JMAG.2014.19.2.140

Modeling of Electrical Transport in YBCO Single Layer Thin Films using Flux Motion Model

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(Received 24 February 2014, Received in final form 31 March 2014, Accepted 15 April 2014)

The electrical transport properties of YBCO single layers thin film have been investigated using different physical techniques. For the purpose, the physical properties are probed numerically with help of simulation modelling. The physical transport properties were also estimated with temperature and magnetic fields limits using thermally-activated flux flow model with some modifications. The result of present simulation modelling indicated that the magnitude of activation energy depends on temperature and magnetic field. The simulations revealed thickness dependent physical transport properties including electrical and magnetic properties of deposited YBCO single layers thin films. Furthermore, it shows the temperature dependence of the pinning energy. In the nutshell, the result can be used to improve the Superconducting Properties (T_c) of the YBCO single layers thin films.

Keywords : HTS, YBCO, CuO, high-T_c, MgO

1. Introduction

During the last few decades, the scientists over the world amplified their efforts to utilize the High Temperature Superconductors (HTS) for several practical considerations. Amongst, improved technology, low cost, improved use efficiency, and indeed high performance of materials are of significant importance. Due to this reason, now a day's most of industries are manufacturing the HTS materials in thin films form for their practical applications. Globally, researchers are also attempting to improve the quality of newly discovered high-T_c oxide superconductors. Industrialists prioritize low cost HTS materials over low temperature superconductors due to their suitable critical temperature when cooled down in liquid nitrogen. Superconductor deposited on insulating material also show the super currents and thus clarifying the closeness effect and nonlinear current-voltage (I-V) characteristics [1-7].

In the present article we have theoretically discussed the factors controlling the current densities along the lattice sites of the single layer YBCO thin films. The most important characteristic of a superconductor is to maintain the maximum electrical current transport density without any resistance at small scale as well as large scale. The same features hold significant practical implications offering transformers, the transmission of power lines, electromagnets, passive devices and Josephson devices. The YBCO like HTS exhibits more complex magnetic flux behavior than low - HTS [8]. The complication associated with magnetic flux in high-T_c superconductors are of great importance. However, the flux pinning system and its relation with dissipative flux motion still need further elaboration for better understanding of the mechanisms. Although, techniques producing low cost fabrication improved the superconducting characteristics of different materials but commercial success is limited that demands the special attention of the researcher's and introduction of obstacles to improve current density is one possibility. Venders and researcher's have made intensive efforts to understand the factors that control the critical current and develop the new fascinating techniques for the measurement of epitaxial filamentary conductors [9-15]. The purpose of this paper is to simulate the different transport properties of YBCO single layer epitaxial films.

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The result generated from the present study would be helpful for the analysis of future experiments with resolution and high field sensitivity.

2. Materials and Methods

The r. f. sputtering and the pulse laser deposition are the film deposition methods used to fabricate the highly quality single layers YBCO films as shown in the Fig. 1. The ultra high vacuum is an important part of the ceramic deposition process and turbo molecular pump can be used to serve the purpose. The difference between the PLD and r. f. sputtering processes the oxides are synthesized with one gas or the mixture of two gasses while the dependency of oxygen gas among both the techniques is influential on the YBCO type material.

In PLD, where the YBCO target is fixed on the position 4-5 cm away from the substrate which is at angle of 45^o from the target material as shown in the Fig. 1(a). The converged laser light hits the YBCO target with high velocity and pulling the atoms and molecules thus energizing them that later headed straight to the substrate MgO. The substrate heater works at different heating ranges mostly from 0^o to 650^o depending upon the system of PLD that compel the experimentalist to perform annealing ex-situ under oxygen for YBCO.

In r. f. sputtering the YBCO target of diameter 3-5 cm is etched by energetic particles positioned at 17-18 cm away from the substrate target as shown in the Fig. 1(b). Thus, the chamber holds the mixture of oxygen and argon gases during the ablation process for the formation of plasma growth. The collision cascades get going inside the YBCO target by the incident ions, those cascades shrink back and when reached at the surface with the energy higher than their binding energy on the surface particles, as a result the atoms ejected from the YBCO target surface, move straight along the substrate target MgO and deposition occur in the form of layer.

3. The Results and Discussion

3.1. Thickness

The thickness of the single layer YBCO is estimated by the equation

$$d_{Thick} = \lambda(t)\sin\theta\ln\left(1+\frac{I_{KK}}{\beta_{RR}}\right). \quad (1)$$

The λ represents attenuation length of the photoelectrons, the I_{KK} indicates indefinite film ratio, β_{RR} is the relative intensity of single layer YBCO films and angle θ is in between the incident light and the YBCO target. The Fig. 2, speaks about the inverse proportionality among the thickness and the relative intensity of the single layer. The thickness is directly proportional to incident angle and mostly due to the knoted energy of the excited atoms. For YBCO single layers deposition the relative intensity of the excited particles increased during the deposition process which results in epitaxial growth having strong binding energy of atoms and molecules, while their response toward the electrical transport properties is enough conducting [4].

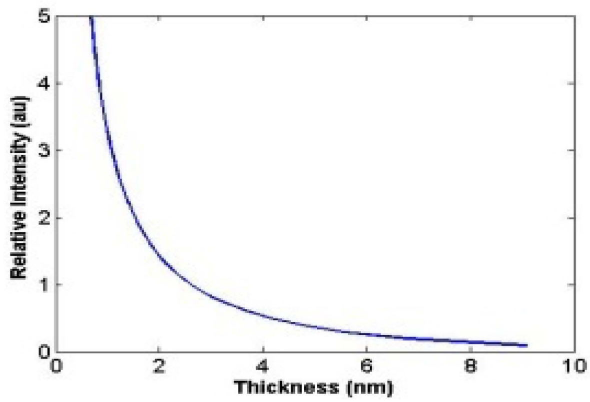
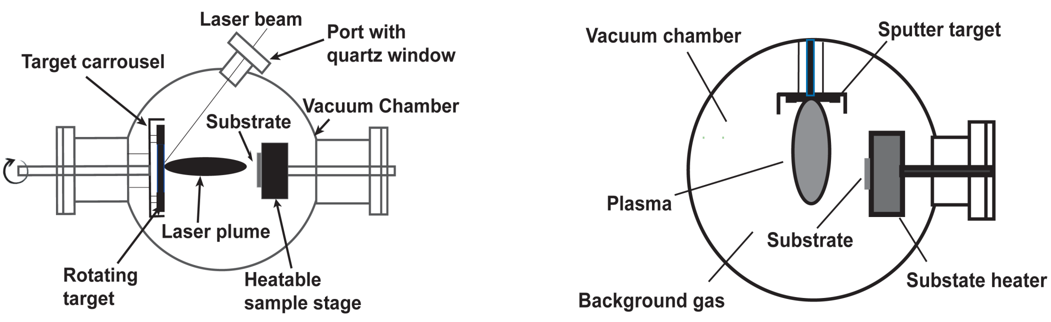


Fig. 2. (Color online) The thickness versus relative intensity of YBCO single layer film.



(a) (b)

Fig. 1. (Color online) (a) The Pulse Laser Deposition setup (b) R. F. Sputtering Setup.

3.2 Electrical Properties

The four-point probes method is experimentally responsible for the measurements of resistance in superconductors. In these experiments, we model the physical properties of YBCO single layer thin films under thermally-activated flux flow motion. The transport properties are strongly associated with high-J_c values of single layer thin films structure. The current discussion includes the current density J_{CD} dependencies on effective pinning potential U_{EPP}. The results produced are as a function of magnetic flux B and temperature T. The dependencies have been found from the standard flux creep model [13]. The flux creep standard model has discussed the flux pinning scaling behavior with high J_{CD} values and is in good agreement with our current results. In the present study the superconducting properties on patterned single layer films are carried out by four point probes measurements [19]. The I-V curves are taken at various temperature values with fixed magnetic field B perpendicular to the ab-axis and parallel to c-axis of the lattice parameters. The in-field resistive transitions using current densities transport within the range of A/cm^2.

In the flux-creep model, the flux bundle hoping frequency is given by

$$\gamma_{hop} = \gamma_{OO} \exp\left[-\frac{U_{OAB}}{KT}\right]\sinh\left[\frac{W_L}{KT}\right]. \quad (2)$$

$$W = J \times B \times V_{FB} \times X_{PP}. \quad (3)$$

The γ_{00} is the characteristic attempts frequency and W_L is the work done by Lorentz driving force opposite to U_{OAB}. The effective pinning potential barrier $U(J, T, B)$ for interpreting the flux motion can be written as

$$U = U_{OAB} - W_L. \quad (4)$$

The U_{OAB} is the activation barrier of range X_{PP} and also J_{CD} dependent. The V_{FB} is the flux bundle volume. In the current case, U_{OAB} is not consider to be a constant term.

If a flux line lattice (FLL) moves, an electric field is $E = B\ X\ V/C$ is produced by driving force and the resulting non linear current densities curves (E_{JCD})

$$E_{JCD} = E_{OO} \exp\left[-\frac{U_{OAB}}{KT}\right]\sinh\left[\frac{W_L}{KT}\right]. \quad (5)$$

Where $E_{OO} = (\gamma_{00} B x_H)/C$ and $U_{OAB} = U_{OAB}(J, T, B)$; x_H is the average hoping distance. During the superconducting state the superconducting current density J_{SCD} is remunerated by the pinning force.

$$U_{OAB}(J_{SCD}, T, B) = W = J \times B \times V_{FB} \times X_{PP}. \quad (6)$$

The J_{SCD} is some function of T and B from theoretical interpretation [20-22].

For the case of small current density and large current density, we can consider the Equ. (2). The W is directly proportional to J while U_{OAB} decreases [11] with V_{FB} such that W = U_{OAB} (J_{SCD}) at $J_{CD} = J_{SCD}$. In term of small current the following equation is as under.

$$J = J_{CD}/J_{SCD} \text{ where } U_{OO} \propto \exp(J_{CD}/J_{SCD}) \quad (7)$$

By using the above equation leads to a solution

$$U_{OAB}(J, T, B) = U_{OAB}(T, B)\exp(-j). \quad (8)$$

The general result of Equ. (4) and (8) are as under

$$E_{JCD} = E_{OO} \exp\left[-\frac{U_{OAB}(T, B)}{KT}\exp(-J)\right] \sinh\left[\frac{JU_{OAB}(T, B)}{KT}\exp(-J)\right]. \quad (9)$$

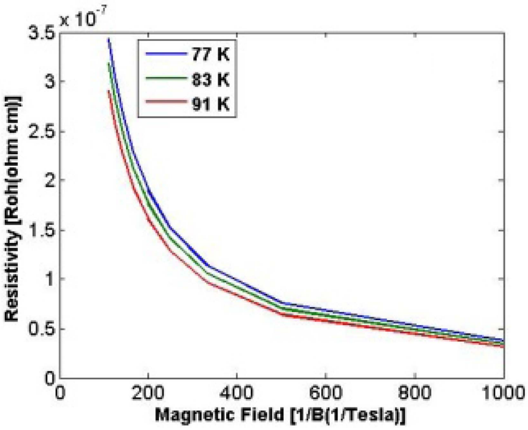
The above equation describes the transport properties over electric current densities, magnetic fields and liquid nitrogen temperatures.

The electrical resistivity was measured by the equation

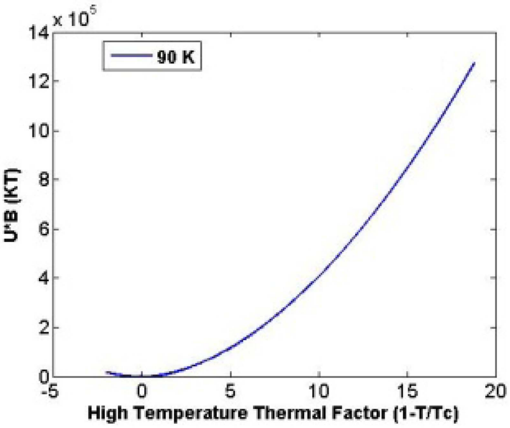
$$\rho = \frac{E_{JCD}}{J} = \frac{E_{OO}(T, B)}{J_{SCD}(T, B)} \times \frac{U_{OAB}(T, B)}{KT} \times \left[1 + j\left[\frac{U_{OAB}(T, B)}{KT} - 1\right]\right] \times \exp\left[-\frac{U_{OAB}(T, B)}{KT}\right]. \quad (10)$$

In the following Fig. 3, we portray magnetic field dependent resistivity of epitaxial single layer film. The resistivity with the fix temperature range of 77 K, 83 K, and 91 K gives a measure of the quality of a thin film. The slope of resistivity measurement when perform on c-axis orientation gives directly the quantity U_{OAB}/KT with the loss decreasing current values of J. The width of the YBCO transitions gives a high degree of homogeneity measure of epitaxial single layer thin films while the presence of higher resistivity at high field can be used as an indication of in homogeneities and disorder throughout the entire films and vice versa. The four point probes resistivity measurement in YBCO films have great importance especially when studying the effect of controlled induced disorders.

The Fig. 4, is linked with E-J curve that are taken at $T_c = 90$ K with magnetic field values 1, 2, 3, 4. The curves have positive curvature with increasing current values and are nearly non linear in their response. While the curvature becomes negative with lower magnetic field values approximately less than 1T and seems to be linear with high current densities. The power law of current dependencies in Equ. (9) showed rapid decrease when the magnetic field is changed from 1T to the higher values



(a)



(b)

Fig. 3. (Color online) (a) The plot of ρ vs 1/B at fixed values of Tc (b) The activation barrier as a product of B vs High temperature thermal factor.

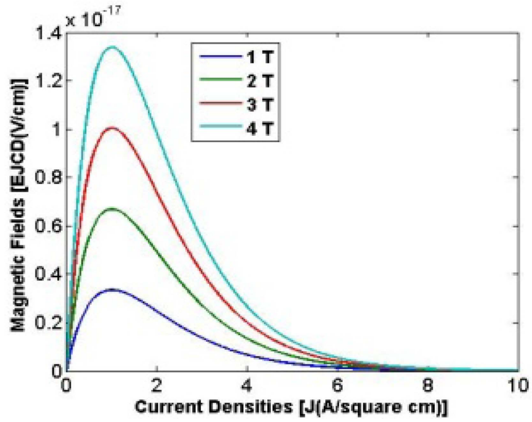


Fig. 4. (Color online) The E vs J with different magnetic fields values.

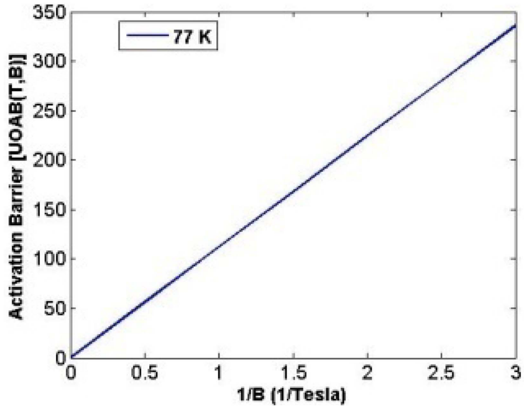


Fig. 5. (Color online) The activation barrier vs magnetic fields.

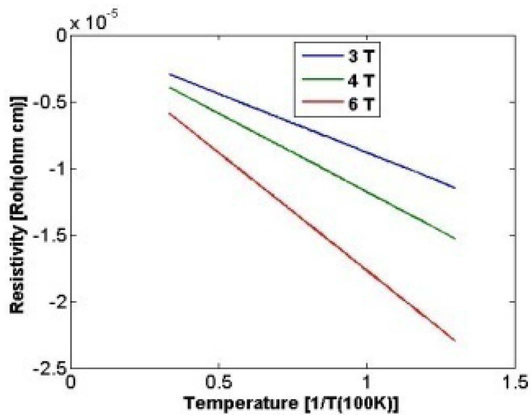


Fig. 6. (Color online) The plots of resistive transitions between ρ vs T with different magnetic fields values.

and the humps become more sharper and become saturated with the increasing values of J. Results presented in Fig. 5, shows the saturation of U_{0AB} at low values of B and vice versa. The results have logarithmic sensitivity to the temperature dependencies of E_{OO} and J_{SCD} but strongly influenced by the Temperature and Field dependencies of $U_{OAB}(T, B)$.

The linear dependence of electrical resistivity along the CuO_2 planes over a large temperature range is one of the exotic feature of YBCO type materials. The typical resistivity vs. temperature curves are shown in Fig. 6, on different magnetic field values 3, 4 and 6 Tesla. The slope of the normal-state resistivity is proportional to the carrier concentration. The results are in good agreement with the value of extrapolated normal-state resistivity to zero temperature, showing the temperature difference distance between the 90% and 10% of the value. Finally, it can be observe that the value of T_c is a measure of oxygen level along the planes. The recent theoretical resistivity vs. temperature values are portraying on different field values and various currents densities. At low temperature the resistivity is thermally activated and U_{0AB} is strongly current dependent. The initial rise of resistivity and its gradual decay with decreasing temperature in the flux flow region indicate that thermally activated flux creep is observed at the lower values of temperature. Moreover the superconductivity at such high temperatures cannot be described by only considering that phonons are the significant excitations that is couple with electron for the transport phenomenon.

3.2 Magnetic Properties

The M/H ratio is responsible for the susceptible magnetic moments of a particular high-T_c superconducting layers. The relative permeability is consider to be zero and the susceptibility is negative for high-T_c single layers thin film superconductor. For the HTS material the magnetization is in opposite to the applied field. The susceptibility measurements can differentiate between the superconducting and the normal material. Therefore, susceptibility measurements are crucially important physical property of the YBCO materials. The appearance of the mixed state during the measurements of high-T_c materials is consider to be disappearance of dc electrical resistivity. However if the specimen most probably in case of single layers prepared under low pressure and low temperature, have very small conducting filaments and consider to be whole current carrying superconductor, therefore the susceptibility measurements are preferable over the dc-electrical resistivity measurements. The reference signal from the signal generator and the applied signal from the secondary coil align in phase then the real part of the actual susceptibility is recorded. This sharp drop over any temperature range represent the T_c. The determination of ac-susceptibility is one of the best way of checking homogeneity and the granular nature of the single layer thin films structures.

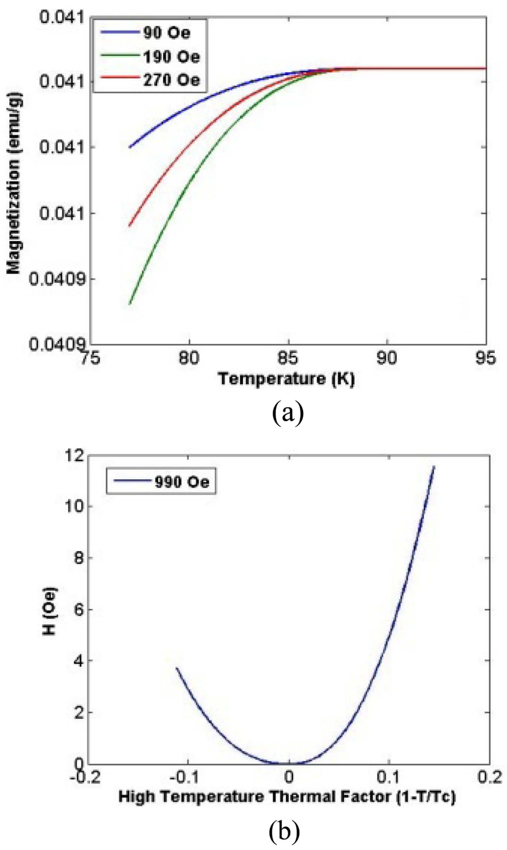


Fig. 7. (Color online) The plot of (a) Magnetization over applied fields vs temperature (b) High temperature thermal factor vs applied field.

The superconducting magnetic behavior of the single layer thin film is shown in the Fig. 7, portraying the magnetic response of magnetization on changing temperature values with different applied field values. The transition T_c is clearly above 89 K showing the YBCO single layer metallic behavior. In contrary some factors are non conducting contacts, week coupling between the grains, the inclusion of extra phases, or the deficiency of oxygen from the lattice sites can cause the reduce T_c width of transition.

However in the present simulation we reached to T_c so aforementioned factors are not important.

4. Conclusion

Simulation modeling successfully conducted to describe the pure YBCO single layer thin films structure using Physical transport properties. In this study, the superconducting transport properties of high-J_c single buffer layer of pure YBCO on MgO substrate were investigated numerically with the help of simulation modeling. The physical properties are quantitatively and self-consistently described in term of a model of thermally-activated flux motion under the magnetic fields and temperatures limits. The higher the resistivity at lower field and low temperature also depend upon contact strength between the layer and the probes. I-V characteristic are directly related to the activation energy and we have obtained the temperature dependence. The results further predicted that the resistance is thermally-activated with activation energy being current dependent. Moreover, the results depicted that transport occur strongly depending upon thickness of the film, the orientation and strength of the field. The research finding are very important theoretical and experimental implications particularly electron transport in YBCO epitaxial layers.

Acknowledgements

The authors would like to thank to Higher Education Commission of Pakistan (HEC) for the Partial Support Program and Universiti Putra Malaysia.

References

[1] A. N. Jannah, S. A. Halim, H. Abdullah, Def. and Diff. Forum, Def. and Diff. in Metals **293**, 47 (2009).
[2] C. F. Dee, J. D. Lee, C. H. Sow, B. Y. Majlis, A. Hamzah, and H. Abdullah, Mater. Res. Innov. **13**, 135 (2009).
[3] L. S. Ewe, I. Hamadneh, H. Salama, N. A. Hamid, S. A. Halim, and R. Abd-shukor, App. Phy. **A 95**, 457 (2009).
[4] U. D. Fasih, S. A. Halim, A. Kamalianfar, K. P. Lim, Z. A. Talib, M. Shahid, and M. G. Ashiq, J. Ovo. Res. **8**, 9 (2012).
[5] L. Liu, Z. Zhao, H. Li, and Y. Li, IEEE Trans. Appl. Supercond. **20**, 1561 (2010).
[6] A. Augieri, V. Galluzzi, G. Celentano, A. A. Angrisani, A. Mancini, A. Rufoloni, A. Vannozzi, E. Silva, N. Pompeo, T. Petrisor, L. Ciontea, U. Gambardella, and S. Rubanov, IEEE Trans. Appl. Supercond. **19**, 3399 (2009).
[7] E. Zeldov, N. M. Amer, G. Koren, A. Gupta, M. W. McElfresh, and R. J. Gambino Appl. Phys. Lett. **56**, 680 (1990).
[8] D. D. Hughes, Low. Temp. Phys. **27**, 967 (2001).
[9] Y. Yeshurun and A. P. Malozemoff, Phys. Rev. Lett. **60**, 2202 (1988).
[10] M. V. Feigelman, V. B. Geshkenbein, A. I. Larkin, and V. M. Vinokur, Phys. Rev. Lett. **63**, 2203 (1989).
[11] T. Natterman, Phys. Rev. Lett. **64**, 2454 (1990).
[12] P. H. Kes, J. Aarts, J. V. D. Berg, C. J. V. D. Beek, and J. A. Mydosh, Supercond. Sci. Technol. **1**, 242 (1989).
[13] E. Zeldov, N. M. Amer, G. Koren, A. Gupta, M. W. McElfresh, and R. J. Gambino Appl. Phys. Lett. **56**, 680 (1990).
[14] J. R. Thompson, Y. Sun, and F. H. Holtzberg, Phys. Rev. B (RC). **44-1**, 469 (1991).
[15] A. K. Nawazish, U. D. Fasih, and A. A. Khurram, Physic. C **417**, 119 (2005).
[16] M. Navasery, S. A. Halim, G. Bahmanrokh, M. H. Erfani, N. Soltani, A. Dehzangi, A. Kamalianfar, U. D. Fasih, S. A. Abdolmohammadi, S. K. Chen, K. P. Lim, L. A. Mehdipour, and A. Anuar, Int. J. Electrochem. Sci. **8**, 6905 (2013).
[17] U. D. Fasih, A. K. Nawazish, and S. A. Halim, Bulk and Thin Films $Cu_{1-x}Tl_xBa_2CaCu_20_{8-y}$ Superconductors Introduction and Properties, Germany Lambert. Acad. Pub. (LAP) AG & Co. KG., Germany (2012) p. 1.
[18] D. H. Lowndes, D. P. Norton, J. W. McCamy, R. Feenstra, J. D. Budai, D. K. Chiristen, and D. B. Poker, In High Temperature Superconductors: Fundamental Properties and Novel Materials Processing, edited by D. Christen, J. Narayan and L. Schneemeyer, Mat. Res. Society, (Pittsburg, America) (1979) p. 143.
[19] A. I. Larkin and Y. N. Ovchinnikov, J. Low. Temp. Phys. **34**, 409 (1979).
[20] S. Zhu, D. K. Chirsten, C. E. Klabunde, J. R. Thompson, C. E. Jones, R. Feenstra, D. H. Lowndes, and D. P. Norton, Phys. Rev. **B 46**, 5576 (1992).
[21] I. Felner and Y. Kopelevich, Phys. Rev. **B 79**, 233409 (2009).