Bogoliubov Laboratory of Theoretical Physics Joint Institute for Nuclear Research

International Conference

DUBNA-NANO2012

July 9-14,2012 • Dubna, Russia

Section

JOSEPHSON JUNCTIONS

abstracts online

CHARGE DENSITY WAVES AND ORIGIN OF THE BRANCHING IN INTRINSIC JOSEPHSON JUNCTION

Yu. M. Shukrinov[1], **E. Hamza**[2], **H. Abdelhafiz**[3] **and K. Hegab**[2]

[1]*Joint Institute for Nuclear Research, BLTP, Dubna, Russia*
[2] *Cairo University, Cairo, Egypt*
[3]*Nile University, Smart Village, Cairo, Egypt*

E-mail: hazem.abdelhafiz@nileu.edu.eg

We study the longitudinal plasma wave transformation to the charge density wave (CDW) in the parametric resonance region, by numerically calculating the charge oscillation on a stack of IJJ in the framework of capacitively coupled Josephson junctions model with diffusion current [1]. We investigate the electric charge oscillations in the stacks both with even and odd number of junctions. An interesting behavior is observed in the end part of the breakpoint region at a transition from the outermost branch to some other branch of CVC. A new feature appears around this point: the chaotic behavior is changed by regular oscillations on all layers. A charge on the different layers oscillates with an amplitude smaller than in LPW around definite charge values forming a standing CDW.

In Ref.[2] was shown that the reason for the multiple branching in the intrinsic Joseph son junction is due to the freezing of the collective LPW mode into the static CDW. We analyze different types of transitions from the outermost branch and between other branches to study the freezing of LPW to CDW in the stacks with different number of IJJ.

References

[1] Yu.M. Shukrinov, F. Mahfouzi and P. Seidel, Equidistance of branch structure in capacitively coupled Josephson junctions model with diffusion current. Physica C, **449**, 62-66 (2006).

[2] M. Machida, T. Koyama, M. Tachiki, Instability of the longitudinal plasma oscillations and intrinsic AC Josephson effects in Josephson coupled high-Tc superconductors. Physica C, **300**, 55-60 (1998).

ANALYSIS OF CHAOS IN COUPLED JOSEPHSON JUNCTIONS

A.E. Botha[1], **Yu. M. Shukrinov**[2] **and M.R. Kolahchi**[3]

[1]*Department of Physics, University of South Africa, P.O. Box 392, Pretoria 0003, South Africa*
[2]*Joint Institute for Nuclear Research, BLTP, Dubna, Russia*
[3]*Institute for Advanced Studies in Basic Sciences, P.O.Box 45195-1159, Zanjan, Iran*

E-mail.: bothaae@unisa.ac.za

It is demonstrated through numerical simulation that stacks of coupled Josephson junctions can exhibit interesting chaotic behavior. A detailed analysis of this chaos is made, including the computation of Lyapunov exponents, Poincaré sections, bifurcation diagrams, etc. The variation in chaotic features with dissipation parameter is also investigated through the use of correlation functions and polar diagrams. Lastly the effect of the number of junctions in the stack and boundary conditions is investigated, leading to the observation of abrupt transitions between hyperchaotic, chaotic and quasi-periodic behavior in different systems.

SHAPIRO AND PARAMETRIC RESONANCES IN COUPLED JOSEPHSON JUNCTIONS

M. A. Gaafar[1,2], **Y. M. Shukrinov**[1] **and A. Foda**[3]

[1]*BLTP, JINR, Dubna, Moscow Region, 141980, Russia*
[2]*Department of Physics, Faculty of Science, Menoufiya University, Egypt*
[3]*Nile University, Smart Village, Cairo, Egypt*

E-mail: mgaafar@theor.jinr.ru

The effect of microwave irradiation on the phase dynamics of the system of coupled Josephson junctions at parametric resonance condition [1, 2] is investigated. The current-voltage characteristics (CVC) of the system are calculated at different values of microwave frequency and amplitude. Influence of the microwave irradiation on the time dependence of the electric charge in superconducting layers is studied. The effect of triplet resonance between microwave, Josephson, and longitudinal plasma wave frequencies on CVC and charge dynamics of the system is illustrated. We demonstrate a strong effect of the microwave radiation on the width of the resonance region [3]. The effect of the coupling between junctions on the Shapiro steps is shown. We compare results obtained in different theoretical models with existing experimental data.

References

[1] Yu. M. Shukrinov and F. Mahfouzi, Phys. Rev. Lett. **98**, 157001 (2007).
[2] Yu. M. Shukrinov, F. Mahfouzi, M.Suzuki, Phys.Rev.B, **78** 134521 (2008).
[3] Yu. M. Shukrinov, M. Hamdipour and M. R. Kolahchi, Phys.Rev.B, **80**, 014512 (2009).

QUANTUM TERAHERTZ ELECTRONICS (QTE): GENERATION OF COHERENT RADIATION FROM MESA STRUCTURES OF HIGH TEMPERATURE SUPERCONDUCTING BI212 INTRINSIC JOSEPHSON JUNCTIONS

K. Kadowaki[1,2,3], **M. Tsujimoto**[2,3,4], **K. Delfanazari**[2,3,4], **T. Kitamura**[2,3,4], **M.Sawamura**[2,3,4], **T. Kashiwagi**[1,2,3], **H. Minami**[1,2,3] **and Richard A. Klemm**[4]

[1]*Division of Materials Science, Faculty of Pure & Applied Sciences, University of Tsukuba, 1-1-1, Tennodai, Tsukuba, Ibaraki 305-8573, Japan*
[2]*CREST-JST & WPI-MANA at NIMS*
[3]*Graduate School of pure & Applied Sciences, University of Tsukuba, 1-1-1, Tennodai, Tsukuba, Ibaraki 305-8573, Japan*
[4]*Department of Physics, University of Central Florida, 4000 Central Florida Blvd., Orlando, FL 32816-2385, USA*

E-mail: kadowaki@ims.tsukuba.ac.jp, Web page: http://kadowaki.ims.tsukuba.ac.jp/

The discovery of THz radiation from a mesa structure of the intrinsc Josephson junction system fabricated by the high temperature superconductor $Bi_2Sr_2CaCu_2O_{8+\delta}$ single crystal has awaken a substantial interest in the field of superconductivity because this may possibly overcome the problem of the teraherz gap existing in the electromagnetic spectrum[1]. We show experimentally that the mechanism of radiation is really due to the ac-Josephson effect working coherently at each individual intrinsic Josephson junctions in the CuO_2-Bi_2O_2-CuO_2 sandwitch structure. Although the geometrical cavity resonance is known to work, it only helps the radiation intensity at certain resonance freuencies[2]. We recently have measured the radiation line width by using mixcer technique at the center frequency of about 600-900 GHz since the synchronization mechanism of the individual intrinsic Josephson junctions can be understood by analyzing the line width of the emitted radiation[3]. We also show the way how to make stronger radiation intensity for the practical use of THz radiation[4] and our preliminary experiment will be shown for applications[5]. In summary the quantum terahertz electronics (QTE) will be described. **References**

[1] L. Ozyuzer, et al., Science 318 (2007) 1291, K. Kadowaki et al., Physica C **468**, 634 (2008).
[2] M. Tsujimoto et al., Phys. Rev. Lett. **105** 037005 (1-4) (2010).
[3] T. Kashiwagi et al., Jpn. J. Appl. Phys. **51**, 010113 (2012).
[4] N. Orita et al., Physica C **470**, S786 (2010).
[5] M. Tsujimoto et al., submitted to J. Appl. Phys.

SPATIAL DISTRIBUTION OF ELECTRICAL CURRENTS IN HIGH-TC GRAIN BOUNDARY JUNCTIONS

M.M. Khapaev[1], **M.Yu. Kupriyanov**[2], **Y. Y. Divin**[3] **and V. N. Gubankov**[4]

[1]*Dep. of Numerical Methods, VMK, Moscow State University, Vorob'evy Gory, 119992, Moscow, Russia*
[2]*Institute of Nuclear Physics, Moscow State University, 119992 Vorob'evy Gory, Moscow, Russia*
[3]*Peter Grnberg Institute, Research Centre Jlich, Leo-Brandt Str. 1, 52425 Jlich, Germany*
[4]*Kotel'nikov Institute of Radio Engineering and Electronics, Russian Academy of Sciences, Mokhovaya 11-7, 125009 Moscow, Russian Federation*

E-mail: vmhap@cs.msu.su, Web page: http://vm.cs.msu.su/

It is well known that strong anisotropy of high-Tc superconducting materials should be taken into account during analysis of electrical data. In more complicated case of high-Tc grain boundary (GB) junctions, consisting of anisotropic high-Tc electrodes and a tunneling barrier at the grain-boundary interface, a simply approach, where these GB junctions are biased by homogeneously distributed electrical currents, may not be valid. We have developed a self-consistent method for calculations of spatial distributions of electrical currents in high-Tc grain boundary (GB) junctions. It was found that anisotropy inside high-Tc superconducting electrodes results in the effects, which previously was not taken into account for the data interpretations. Even in a nanowire composed from two single-crystalline high-Tc electrodes separated by a [100] tilt GB, an assumption of a uniform distribution of the normal current over the film thickness generally does not work and is valid only in the limit of extremely small conductivity of GB interface. There are a significant redistribution of current over the thickness of the superconducting electrodes in the vicinity of the grain boundary. This redistribution may be accompanied by substantial focusing of currents on the top or bottom part of GB thickness, and generation of vortex currents around GB which result in selfbiasing of GB junctions by magnetic field induced by these vortex currents. It is shown that twinning or variation of geometrical shape of GB electrode may also leads to intensive redistribution of a current and nucleation of localized magnetic fields inside superconducting electrodes.

This work has been supported by RFBR project 11-07-12023-ofi-m-2011 and, in part by Swedish Institute Visby Grant 00910/2011.

SOLITON-ANTISOLITON ANNIHILATION AND BREATHER SELF-OSCILLATIONS IN THE COUPLED SINE-GORDON EQUATION

V. M. Krasnov

Department of Physics, AlbaNova University Center, Stockholm University, SE-10691 Stockholm, Sweden

Solitons are elementary particles of the sine-Gordon equation, in the sense that they are quantized and do not spontaneously decay. In the sine-Gordon equation solitons/antisolitons behave as relativistic particles and in the absence of perturbation do not annihilate. Here I consider soliton-antisoliton collisions in the coupled sine-Gordon, which is not Lorentz invariant. It is shown that in such a system soliton-antisoliton pair annihilates even in the absence of perturbations. The annihilation occurs via radiative losses by emission of plasma waves (photons). In a dc-driven case, a similar phenomenon leads to a strong coupling between the coupled soliton-antisoliton pairs, breathers, and propagating linear waves, which may lead to self-oscillations. Breather self-oscillations create a mechanism of intense high-frequency electromagnetic wave generation from spatially uniform stacked Josephson junctions at zero magnetic field [1]. It is argued that this mechanism explains all major features of zero-field radiation from intrinsic Josephson junction, naturally formed in single crystals of layered $Bi_2Sr_2CaCu_2O_{8+x}$ (Bi-2212) high-temperature superconductor.

Finally, different mechanisms of coherent emission from Bi-2212 mesas are reviewed and the roles of geometrical resonances [2], dynamic radiative boundary conditions [3] and optical infrared phonon [4] in achieving coherent high power emission from stacked Josephson junctions are discussed.

[1] V.M. Krasnov, Phys. Rev. B. 83, 174517 (2011).

[2] S.O. Katterwe, A. Rydh, H. Motzkau, A.B. Kulakov, and V.M. Krasnov, Phys. Rev. B. **82**, 024517 (2010).

[3] V.M. Krasnov, Phys. Rev. B. **82**, 134524 (2010).

[4] S.O. Katterwe, H. Motzkau, A. Rydh, and V.M. Krasnov, Phys. Rev. B. **82**, 100510(R) (2011).

PECULIARITIES OF PHASE DYNAMICS OF INTRINSIC JOSEPHSON JUNCTIONS SHUNTED BY RLC CIRCUIT

I.R. Rahmonov[1,3], K.V. Kulikov[1,2], Yu. M. Shukrinov[1,2,3] and K. ElGamal[4]

[1]*BLTP, Joint Institute for Nuclear Research, 141980 Dubna, Russia*
[2]*Department of Theoretical Physics, International University of Dubna, 141980, Dubna, Russia*
[3]*Umarov Physical Technical Institute, 734063 Dushanbe, Tajikistan*
[4]*Nanotechnology Research Center, Nile University, Smart Village, Cairo,12677 Egypt*

E-mail: kirknemec2@mail.ru

The intrinsic Josephson junctions (IJJ) in high TC superconductors can be used as terahertz electromagnetic waves sources in the superconducting electronics [1]. One of the important problems is to synchronize all junctions in a stack. Some theoretical models were proposed which demonstrated that resistive-inductive-capacitive (RLC) shunting leads to synchronization all junctions [2, 3]. When $\omega_J = 2\omega_{LPW}$, where ω_J and ω_{LPW} are Josephson and longitudinal plasma wave frequencies, respectively, a parametric resonance in the system is appeared and amplitude of the electric charge in the superconducting layers is increased [4]. We study the phase dynamics of the IJJ stack shunted by RLC resonant circuit in the framework of models with capacitive coupling [5, 6]. The CVC of IJJ array with LC shunting is numerically calculated.

The influence of LC shunting on CVC and parametric resonance in the system is discussed. In the case of LC shunting the step structure in CVC appears, when the value of Josephson frequency approaches to the frequency of the LC circuit [2, 3]. The location of the step structure depends on parameters of the LC circuit. Double resonance appears when the step structure approaches the parametric resonance region.

References

[1] L. Ozyuzer et al, Science, 318, 1291, (2007).
[2] M.Tachiki, K.Ivanovic, K.Kadowaki, T.Koyama, Phys.Rev. B, **83**,014508 (2011).
[3] T.Zhou, J. Mao, H. Cui, X. Zhao, L. Fang, S. Yan, Physica C, **469**, 785 (2009).
[4] Yu. M. Shukrinov and F. Mahfouzi, Supercond. Sci. Technol., **20**, S38-S42 (2007).
[5] M.Machida, T. Koyama, A.Tanaka, and M.Tachiki, Physica C, **330**, 85 (2000).
[6] Yu. M. Shukrinov, F. Mahfouzi, P. Seidel, Physica C, 449, 62 (2006).

DISTRIBUTED JOSEPHSON JUNCTION BETWEEN MULTIBAND SUPERCONDUCTORS

V.V. Kurin

Institute for Physics of Microstructures, RAS 603950, N. Novgorod, GSP-105, Russia

E-mail: kurin@ipm.sci-nnov.ru

It is well known that multifolded Fermi surface superconductors may feature the so-called Leggett modes, that essentially are collective excitations of phase difference of order parameters in different bands. Multiband superconductors, in accordance with the modern view, include the conventional ones such as Nb, and the recently discovered novel superconductors as MgB_2 and the FeAs based ones. Excitation of the Leggett modes in lumped Josephson junctions was earlier considered by some authors theoretically and observed experimentally.

Here we propose a hydrodynamic self-consistent model describing the dynamics of distributed Josephson junctions between multiband superconductors. The dynamics of such Josephson junction is described by the equation that in a Fourier representation has the form

$$\frac{\hbar}{8\pi e(d+2\lambda)}\left[c^2\chi^2 - \frac{\varepsilon\omega^2}{d}\left(d - \frac{2icZ(\omega,\chi)}{\omega}\right)\right]\Psi(\omega,\chi) + j_x(\omega,\chi) = j_{ext}\,. \qquad (1)$$

Here the dynamic phase variable variable Ψ is defined via the magnetic field flux penetrating the dielectric layer by operator relation $\hbar\partial_x\psi = 2ec^{-1}(d+2\lambda)B_z$, and $Z = E_x / B_z$ is the impedance at the dielectric interface, j_y is the tunnel current through interlayer, that is a sum of the quasiparticles current and supercurrent. The tunnel current should be found from boundary conditions. The supercurrent is defined by standard way via phase jumps of order parameters $j_s = \sum_{i,j} j^c_{i,j}\sin(\theta^L_i - \theta^R_j)$, where $\theta^{L,R}_i(y = \pm d/2)$ are the limiting phase values of superconducting order parameters on different sides of the Josephson junction and $j^c_{i,j}$-matrix of critical currents. A closed model of the Josephson dynamics would take the knowledge of impedance and of relation between the Josephson phase jumps used to define supercurrent and fields inside the junction. These quantities are sought by solving the outer problem. On such a way we will find expressions impedance Z and for phase differences $\theta^R_i - \theta^L_j = (\hat{H}_i - \hat{H}_j)\psi$ and come to expression for supercurrent through the junctions.

Thus we have derived an equation describing the dynamics of a distributed Josephson junction between multiband superconductors and studied the excitation of Leggett modes by dense chain of moving Josephson vortices.

ELECTROMAGNETIC WAVE EMISSION FROM INTRINSIC JOSEPHSON JUNCTION STACKS: A REVIEW OF DIRECT NUMERICAL SIMULATION

H. Matsumoto[1], T. Koyama[1], Y.Ohta[2] and M. Machida[3]

[1]*IMR,Tohoku University, 2-1-1 Katahira Aoba-ku, Sendai, Japan 980-0000*
[2]*RIKEN Complete address (italicTimes New Roman, 10pt)*
[3]*CCSE, Japan Atomic Energy Agency, Kashiwanoha Kashiwa-shi Chiba, Japan*

E-mail: machida.masahiko@jaea.go.jp

Since the discovery of intrinsic Josephson effects in High-Tc cuprate superconductors, a tremendous number of theoretical and experimental studies have been made to clarify the coupling nature between stacked junctions. The reason comes from an expectation that Josephson junctions stacked in atomic-scale synchronize and high-power electromagnetic wave radiates. Consequently, two types of couplings, called "inductive and capacitive couplings" have been so far established.

On the basis of the inductive coupling, several papers suggested that THz high-power emission is possible by using Josephson vortex flow states in the presence of layer parallel magnetic field and c-axis transport current. However, there has been no clear evidence of the emission in vortex flow states, although a few works found out only the sign.

Afterwards, Ozyuzer et al., reported that they successfully observe a clear emission from intrinsic Josephson junctions [1]. The situation was rather an unexpected one, since the magnetic field is not applied and the employed size is much larger than the experimental trends at that time.

In this presentation, we review a history of the quest of the high power electromagnetic wave emission from intrinsic Josephson stacks before and after the Ozyuzer's work [1] from a theoretical and numerical view. Especially, we would like to emphasize that direct numerical simulation techniques [2] on multi-scale dynamical problems between inside and outside the junction have fully developed by authors.

References

[1] L. Ozyuzer et al., Science 318, 1291 (2007).
[2] T. Koyama, H. Matsumoto, M.Machida, and Y.Ota, Supercond. Sci. Technol. 24, 085007 (2011).

EFFECTS OF SELF-ASSEMBLED GOLD NANOPARTICLES ON YBA2CU3O7-Δ THIN FILMS AND DEVICES

P. Michalowski[1], C. Katzer[1], F. Schmidl[1] and P. Seidel[1]

[1] *Institut für Festkörperphysik, Friedrich-Schiller-Universität Jena, D-07743 Jena, Germany*

E-mail: P.Michalowski@uni-jena.de, Web page: http://www.physik.uni-jena.de/~tief

During the last years there have been various attempts to manipulate the properties of superconducting thin films by using nanoparticles. We are going to give a short summary of different approaches by other groups.

In our work we prepared $YBa_2Cu_3O_{7-\delta}$ (YBCO) thin films with self-assembled gold nanoparticles on $SrTiO_3$ substrates. We carried out different experiments to determine the effects on the crystallographic properties of the YBCO matrix as well as of the gold nanoparticles. [1]

Furthermore, we investigated how the particles influence the superconducting parameters of the film, e.g. the critical temperature T_C and the critical current density j_C. To ascertain j_C we employed magneto-optical Faraday microscopy. [2]

In addition, the YBCO film was deposited and structured on $SrTiO_3$ bi-crystal substrates, thus producing grain boundary Josephson junctions. We studied those junctions with respect to the normal state resistance R_N, and the dependence of the critical current I_C on the temperature T and the magnetic flux Φ. [3]

Finally, we prepared direct current superconducting quantum interference device (dc-SQUID) gradiometers and embedded gold nanoparticles at well-defined areas such as only the antenna or the SQUID region. We measured the flux noise in a shielded environment using an ac-bias reversal technique and compared it with that of sensors without gold nanoparticles. **References**

[1] V. Grosse, S. Engmann, F. Schmidl, A. Undisz, M. Rettenmayr and P. Seidel *Formation of gold nano-particles during pulsed laser deposition of $YBa_2Cu_3O_{7-\delta}$ thin films*. Phys. Status Solidi RRL, **4**, 97-99 (2010).

[2] C. Katzer, M. Schmidt, P. Michalowski, D. Kuhwald, F. Schmidl, V. Grosse, S. Treiber, C. Stahl, J. Albrecht, U. Hübner, A. Undisz, M. Rettenmayer, G. Schütz and P. Seidel *Increased flux pinning in $YBa_2Cu_3O_{7-\delta}$ thin film devices through embedding of Au nano crystals*. Europhys. Lett.., **95**, 68005 (2011).

[3] P. Michalowski, M. Schmidt, F. Schmidl, V. Grosse, D. Kuhwald, C. Katzer, U. Hübner and P. Seidel *Engineering of $YBa_2Cu_3O_{7-\delta}$ grain boundary Josephson junctions by Au nano crystals*. Phys. Status Solidi RRL, **5**, 268-270 (2011).

RESONANCE FEATURES OF THE COUPLED JOSEPHSON JUNCTIONS: SOME UNSOLVED PROBLEMS

Yu. M. Shukrinov[1], **P. Seidel**[2], **W. Nawrocki**[3], **E. Ilichev**[4], **P. A. Plecenik**[5] **and M.Grajcar**[5]

[1]*BLTP, JINR, Dubna, Moscow Region, 141980, Russia*
[2]*Institut fuer Festkoerperphysik, FSU, Jena, D-07743 Jena, Germany*
[3]*Poznan University of Technology, Poznan, Poland*
[4]*Institute of Photonic Technology, P.O. Box 100239, D-07702 Jena, Germany*
[5]*Department of Experimental Physics, Comenius University, Bratislava, Slovakia*

E-mail: shukrinv@theor.jinr.ru

A short review of the recent results on the phase dynamics and resonance features of a stack of coupled Josephson junctions in layered superconductors is presented. We analyze various resonances in this system and show their influence on current-voltage characteristics. Particularly, we present data demonstrating parametric resonance, Shapiro resonance and resonances related with shunting elements. Moreover, new results on double and triplet resonances are included in this review. We propose new experiments that could reveal the resonance features and consider their possible applications. Some unsolved problems are outlined and discussed in detailed.

INVESTIGATION OF COHERENT TWO-LEVEL DEFECTS USING JOSEPHSON JUNCTION QUBITS

A. V. Ustinov

Physikalisches Institut, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany
National University of Science and Technology MISIS, 119049 Moscow, Russia
E-mail: ustinov@kit.edu

Experimentally measured spectra of Josephson plasma oscillations in tunnel junctions display signatures of coherent coupling to individual microscopic defects acting as two-level systems (TLSs). These defects manifest themselves by avoided level crossings in microwave spectroscopy data reflecting the dependence of the Josephson plasma frequency on the current flowing through the junction. They are currently understood as nanoscale dipole states emerging from metastable lattice configurations in amorphous dielectrics forming the tunnel barrier of the Josephson junction. Such dipolar TLSs couple to the electrical field inside the junction that oscillates at the Josephson plasma frequency.

I will present our recent experiments in which we use a Josephson junction for manipulating the quantum state of a single TLS. These experiments allow to directly measure of the energy relaxation T1 and dephasing T2 times of an individual microscopic dipole-like TLS. Driving Rabi oscillations of the junction tuned close to a resonance with TLS leads to the observation of true 4-level dynamics [1]. The multi-photon spectroscopy allows for direct probing of hybridized states in the combined junction-defect coupled quantum system [2]. New method of direct microwave driving made it possible to study the temperature dependence of coherence times of individual TLSs [3]. Moreover, the observation of TLSs which have much longer coherence times than the macroscopic Josephson qubit renders them interesting for quantum information processing purposes, which we experimentally explored by generating entanglement between two TLSs mediated by the qubit [4]. In the final part of the talk, I will briefly discuss our most recent data on the effect of mechanical stress on the properties of TLSs. **References**

[1] J. Lisenfeld, C. Müller, J.H. Cole, A. Lukashenko, A. Shnirman, and A. V. Ustinov. Phys. Rev. B **81**, 100511 (2010).
[2] P. Bushev, C. Müller, J. Lisenfeld, J. H. Cole, A. Lukashenko, A. Shnirman, and A. V. Ustinov, Phys. Rev. B **82**, 134530 (2010).
[3] J. Lisenfeld, C. Müller, J. H. Cole, P. Bushev, A. Lukashenko, and A.V. Ustinov, Phys. Rev. Lett. **105**, 230504 (2010).
[4] G. J. Grabovskij, P. Bushev, J. H. Cole, C. Müller, J. Lisenfeld, A. Lukashenko, and A. V. Ustinov, New J. Phys. **13**, 063015 (2011).

INTERCONNECTION BETWEEN STATIC REGIMES IN THE LJJS DESCRIBED BY DOUBLE SINE-GORDON EQUATION

P.Kh. Atanasova[1], **E.V. Zemlyanaya**[2] **and Yu.M. Shukrinov**[3]

[1]*University of Plovdiv, FMI, Plovdiv 4003, Bulgaria*
[2]*Joint Institute for Nuclear Research, LIT, Dubna, 141980, Russia*
[3] *Joint Institute for Nuclear Research, BLTP, Dubna, 141980, Russia*

E-mail: atanasova@uni-plovdiv.bg

Long Josephson junctions (LJJ) are attractive objects of theoretical and experimental investigations because of a wide range of applications in nano- and quantum physics.

Important step of the experimental study of the LJJ samples is the measurement of its *static* properties including dependence of the critical current on the external magnetic field [1].

The second harmonic contribution in the LJJ current-phase relation changes the properties of the static magnetic field distributions in the LJJs and inspires new static (homogenious and fluxon) states [2, 3, 4].

We study, numerically, stability properties and bifurcations of the LJJ static regimes within the frame of a model described by the double sine-Gordon equation. The interconnection between different types of magnetic field distributions and the critical current behavior are analyzed in dependence on the second harmonic contribution.

References

[1] E. Goldobin, D. Koelle, R. Kleiner, and R. G. Mints, *Josephson Junction with a Magnetic-Field Tunable Ground State.* Phys. Rev. Lett. 107, 227001 (2011).
[2] E. Goldobin, D. Koelle, R. Kleiner and A. Buzdin, *Josephson junctions with second harmonic in the current-phase relation: Properties of junctions.* Phys. Rev. B., 76, 224523 (2007).
[3] P.Kh. Atanasova, T.L. Boyadjiev, Yu.M. Shukrinov, E.V. Zemlyanaya, P. Seidel, *Influence of Josephson current second harmonic on stability of magnetic flux in long junctions.* J. Phys. Conf. Ser., 248, 012044 (2010).
[4] P.Kh. Atanasova, T.L. Boyadjiev, Yu.M. Shukrinov, E.V. Zemlyanaya, *Numerical Modeling of Long Josephson Junctions in the Frame of the Double Sine-Gordon Equation.* Mathematical Models and Computer Simulations, 3, No. 3, 388397 (2011).