# TT 10: Superconductivity: Tunneling, Josephson Junctions, SQUIDs

Time: Monday 14:00–16:30 Location: HSZ 105

TT 10.1 Mon 14:00 HSZ 105

**Terahertz emission from intrinsic Josephson junctions of high-$T_c$ superconductor Bi2212** — •Lütfi Özyüzer[1,2], Hasan Köseoglu[1], Fulya Türkoglu[1], Cihan Kurter[3], Ulrich Welp[3], Ken E. Gray[3], Alex E. Koshelev[3], Takashi Yamamoto[4], Kazuo Kadowaki[4], Yilmaz Simsek[2], Yuri Koval[2], Paul Müller[2], and Huabing Wang[5] — [1]Department of Physics, Izmir Institute of Technology, Izmir, Turkey — [2]Phys. Inst. III, University of Erlangen-Nurnberg, Germany — [3]Materials Science Division, Argonne National Laboratory, Illinois, USA — [4]University of Tsukuba, Japan — [5]National Institute for Materials Science, Japan

Recent realization of coherent and continuous emission of THz waves from intrinsic Josephson junctions of layered high temperature superconductor $Bi_2Sr_2CaCu_2O_{8+d}$ (Bi2212) is promising to fill electromagnetic spectrum's Terahertz gap [1]. Large area mesas ranging from 300x100 to 300x40 $\mu$m$^2$ with height greater than 1 $\mu$m were formed on Bi2212. Current-voltage and THz emission characteristics were obtained at various temperatures. THz emissions of mesas were studied by Si-composite bolometer and the emission frequencies were obtained.

[1] L. Ozyuzer, A. E. Koshelev, C. Kurter, N. Gopalsami, Q. Li, M. Tachiki, T. Yamamoto, H. Minami, H. Yamaguchi, T. Tachiki, K. E. Gray, W. K. Kwok and U. Welp, Science **318**, 1291 (2007).

*This research is partially supported by TUBITAK (Sci. and Tech. Research Council of Turkey) project number 108T238. L.O. acknowledges support from Alexander von Humboldt Foundation.

TT 10.2 Mon 14:15 HSZ 105

**Fabrication of large $Bi_2Sr_2CaCu_2O_{8+\delta}$ mesas for THz emission** — •Yilmaz Simsek[1], Lütfi Özyüzer[1,2], Yuri Koval[1], Paul Müller[1], and Huabing Wang[3] — [1]Department of Physics, Universität Erlangen-Nürnberg, Erwin-Rommel-Strasse. 1, D-91058, Erlangen, Germany — [2]Department of Physics, Izmir Institute of Technology, Izmir, Turkey — [3]National Institute of Material Science, Japan

Recently, the observation of THz radiation from $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212) single crystals stimulated the research on intrinsic Josephson junctions (IJJ)[1]. We have fabricated large area mesas including many IJJ stacks on Bi-2212 single crystals by electron beam lithography and Ar ion beam etching techniques. As the observed THz emission is probably due to cavity resonances, the fabrication technique was optimized to obtain clear rectangular shapes. We have fabricated large and tall mesas by selective Ar ion beam etching of a Ti layer on Bi-2212. The samples were characterized by dc I-V measurements. We discuss possible resonant features of the I-V characteristics.

[1] L. Ozyuzer, A. E. Koshelev, C. Kurter, N. Gopalsami, Q. Li, M. Tachiki, K. Kadowaki, T. Yamamoto, H. Minami, H. Yamaguchi, T. Tachiki, K. E. Gray, W.-K. Kwok, U. Welp, Science **318**, 1291 (2007).

*L.O. acknowledges support from Alexander von Humboldt Foundation.

TT 10.3 Mon 14:30 HSZ 105

**Laser imaging of hot spots and waves in $Bi_2Sr_2CaCu_2O_8$ intrinsic Josephson junctions** — •S. Guénon[1], M. Grünzweig[1], H. B. Wang[2], J. Yuan[2], A. Iishi[2], S. Arisawa[2], T. Hatano[2], T. Yamashita[2], D. Koelle[1], and R. Kleiner[1] — [1]Physikalisches Institut & Center for CollectiveQuantum Phenomena, Universität Tübingen, Germany — [2]National Institute for Materials Science, Tsukuba3050047, Japan

Motivated by the discovery of coherent Terahertz emission in large sized stacks of $Bi_2Sr_2CaCu_2O_8$ intrinsic Josephson junctions [1] we used low-temperature scanning laser microscopy (LTSLM) to image local electric field distributions of mesa structures patterned on top of $Bi_2Sr_2CaCu_2O_8$ single crystals [2]. In LTSLM a laser beam at position $(x, y)$ on the sample surface locally warms up an area of about a few $\mu$m$^2$. This locally well defined heat distribution changes the electrical properties of the system, which in turn leads to a voltage change $\Delta V(x, y)$ measured globally across the sample. The mesas (330$\mu$m long and 30–70$\mu$m wide) were 1 $\mu$m thick and consisted of about 670 junctions. In the low-bias regime we find clear signatures of standing electromagnetic waves that essentially are in agreement with the THz emission data in [1]. At high bias voltages we observe the formation of a hot spot, which at some currents is accompanied by standing wave patterns interacting with the hot spot.

[1] L. Ozyuzer *et al.*, Science **318**, 1291 (2007)
[2] H. B. Wang, S. Guénon *et al.*, submitted to Phys. Rev. Lett.; arXiv:0807.2749v1 [cond-mat.supr-con]

TT 10.4 Mon 14:45 HSZ 105

**Josephson junctions with ferromagnetic $Fe_{0.75}Co_{0.25}$ and $Cu_2MnAl$ interlayers** — •Dirk Sprungmann[1], Kurt Westerholt[1], Hartmut Zabel[1], and Martin Weides[2] — [1]Institut für Experimentalphysik IV / Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany — [2]IFF Forschungszentrum Jülich, D-52425 Jülich, Germany

We present our studies on SINFS Josephson junctions using $Fe_{0.75}Co_{0.25}$ and $Cu_2MnAl$-Heusler alloys for the F-layer. The junctions with $Fe_{0.75}Co_{0.25}$ represent the case of large magnetic exchange energies in the region of 500 meV. We show that these junctions exhibit an extremely short coherence length $\xi_{F1} = 0.16$ nm and $\xi_{F2} = 0.54$ nm and that the stray fields which emanate from the ferromagnetic layer cause increasing flux trapping effects for thicknesses $d_F \geq 1.1$ nm.

The opposite case with very small exchange energies in the region of several meV is realized in junctions with the Heusler alloy $Cu_2MnAl$. This alloy sputtered at room temperature features a distinct structural disorder which can be reduced by annealing. Because of the correlation between structural order and exchange energy the ferromagnetism can be fine tuned by thermal annealing. We study systematically the influence of the annealing process on the transport properties and correspondingly on the $I_c(d_F)$-characteristic of our junctions.

D. S., K. W. and H. Z. acknowledge financial support by SFB-491, and M. W. by project WE 4359/1-1.

**15 min. break**

TT 10.5 Mon 15:15 HSZ 105

**High frequency properties of Josephson $\pi$-junctions** — •Georg Wild[1,2], Christian Probst[1], Achim Marx[1], and Rudolf Gross[1,2] — [1]Walther-Meissner-Institut, Bayerische Akademie der Wissenschaften, Walther-Meissner-Str. 8, 85748 Garching — [2]Physik Department, Technische Universität München, Garching

Josephson junctions with ferromagnetic interlayer have attracted much interest due to their potential application as $\pi$-phase shift elements. We have developed a self-aligned multilayer process for the fabrication of superconductor/insulator/ferromagnet/superconductor Josephson junctions (S=Nb, I=$AlO_x$, F=NiPd). Our junctions have RCSJ-like current-voltage characteristics and a Fraunhofer diffraction pattern for the magnetic field dependence of the critical current. The dependence of the $I_cR_n$-product on the ferromagnet thickness shows a clear crossover from the zero- to the $\pi$-state. We have determined the plasma frequency of $\pi$-coupled junctions from Fiske resonances. This data is used to explain the different excitations found in microwave spectroscopy experiments at milli-Kelvin temperature.

This work was supported by the DFG via SFB 631 and the Excellence Initiative via NIM.

TT 10.6 Mon 15:30 HSZ 105

**Visualizing supercurrents in 0-$\pi$ ferromagnetic Josephson tunnel junctions** — •Edward Goldobin[1], Christian Gürlich[1], Tobias Gaber[1], Dieter Koelle[1], Reinhold Kleiner[1], Martin Weides[2], and Hermann Kohlstedt[2] — [1]Physikalisches Institut and Center for Collective Quantum Phenomena, Universität Tübingen, Germany — [2]Institute of Solid State Physics, Reserch Center Jülich, Germany

So-called 0 and $\pi$ Josephson junctions can be treated as having positive and negative critical currents. This implies that the same phase shift applied to a Josephson junction causes counterflow of supercurrents in 0 and in $\pi$ junctions connected in parallel provided they are short in comparison with Josephson penetration depth $\lambda_J$.

We have fabricated several 0, $\pi$, 0-$\pi$, 0-$\pi$-0 and 20×(0-$\pi$-) planar superconductor-insulator-ferromagnet-superconductor Josephson junctions and studied the spatial supercurrent density distribution $j_s(x, y)$ across the junction area using low temperature scanning electron microscopy. At zero magnetic field we clearly see counterflow of the supercurrents in 0 and $\pi$ regions. The picture also changes consis-

tently in the applied magnetic field.

TT 10.7 Mon 15:45 HSZ 105

**A universal 0-$\pi$ transition in magnetic triplet superconductor Josephson junctions** — •Philip Brydon[1] and Dirk Manske[2] — [1]Technische Universität Dresden, Dresden, Germany — [2]Max-Planck-Institut für Festkörperforschung, Stuttgart, Germany

The spin of the Cooper pair in a triplet superconductor provides a new degree of freedom in Josephson junction physics. This can be accessed by using a magnetically-active tunneling barrier, leading to a rich variety of unconventional Josephson effects. Using a tunneling Hamiltonian approach, we obtain the currents in an arbitrary triplet superconductor – ferromagnet – triplet superconductor junction, imposing only the condition that the orbital pairing states in the two superconductors are not orthogonal. From this, we predict a sign change of the charge current (a 0-$\pi$ transition) as the orientation of the barrier magnetic moment is varied. We also show that the spin current flows in opposite directions on either side of the junction, and has a phase-independent contribution arising from spin-flip reflection processes. We confirm our results for three different choices of orbital pairing states using Bogoliubov-de Gennes theory.

TT 10.8 Mon 16:00 HSZ 105

**Quantum Dynamics of LC shunted Nb/Al-AlO$_x$/Nb Josephson Junctions** — •Christoph Kaiser[1], Thilo Bauch[2], Floriana Lombardi[2], and Michael Siegel[1] — [1]Institut für Mikro- und Nanoelektronische Systeme, Universität Karlsruhe (TH), D-76187 Karlsruhe — [2]Quantum Device Physics Laboratory, Department of Microtechnology and Nanoscience, MC2, Chalmers University of Technology, S-41296 Göteborg, Sweden

Superconducting systems including Josephson junctions (JJs) are good candidates for studying a macroscopic quantum variable if the system is suitably decoupled from its environment.

We investigate the behavior of this macroscopic quantum variable $\varphi$ in circuits containing a JJ, a capacitor and an inductance. It was shown that $\varphi$ should be confined by a 2-dimensional potential, leading to two energy scales for the quantum levels in the potential wells.

We designed and fabricated such LC-JJ systems with different inductance values, investigated their quantum dynamics and compared the results to the theoretical expectations. The samples were fabricated in Karlsruhe by a thoroughly optimized Nb/AlO$_x$/Nb process employing electron beam lithography. Afterwards, we explored the quantum mechanical energy levels and the tunnelling rates of our samples in a carefully shielded dilution refrigerator in Göteborg.

Our results are in very good agreement with the theoretical predictions. We achieve the quantum regime for our samples and can clearly identify the predicted energy level splittings in our experimental spectroscopy data.

TT 10.9 Mon 16:15 HSZ 105

**Conductance of an array of Josephson junctions in the insulating state** — •Sergey Syzranov[1], Konstantin Efetov[1], and Boris Altshuler[2] — [1]Theoretische Physik III, Ruhr-Universität Bochum, 44801 Bochum, Germany — [2]Physics Department, Columbia University, New York, N.Y. 10027, USA

We study transport in weakly disordered two-dimensional arrays of Josephson junctions in the Coulomb blockade regime. We calculate the conductance of the system at low temperatures and show that it has an activation behaviour with the activation gap close to the charging energy of a single Cooper pair on a superconducting island between the junctions. While a disordered array has a finite conductivity, the conductance of an ideally regular array is independent of its size. The possibility of a new "superinsulating" state is discussed.