MUEXC

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1 *MUEXC* project

MUEXC is a project based on the PRESS-MAG-O apparatus designed to perform experiments on materials under extreme conditions of pressure, magnetic field in a wide temperature range from room temperature down to 4K. It has been designed for fundamental researches and for technological applications of the interest of the Institute. The project is based on a large collaboration between the LNF, the INFN Unit of Florence, the High-pressure Raman group and the Spectroscopy group of the Department of Physics of the *Sapienza* University, the Department of Geological Science of the Roma Tre University and the Department of Physics of the University of Camerino.

In 2012 the main activities of the *MUEXC* collaboration can be summarized as follows:

a) *Maintenance of the cryostat*: after the evaluation of the damage to the PRESS-MAG-O system due to mishandling of the internal transport staff in the LNF, have been carried out the repairs to the cryostat and superconducting magnet. Before the end of the year begins the reassembling of the system to make possible vacuum tests and later operations at low temperature.

b) *Operation on PRESS-MAG-O insert*: we proceeded in the final commissioning of the PRESS-MAG-O insert.

2 Maintenance of the cryostat

The cryostat has been repaired to the DG-Technology company that has realized the system. Moreover, operation, reliability and safety of the superconducting magnet have been tested by the manufacturer of the magnet: the AMI Inc. in USA, where it has been control the superconducting switch of the magnet and it has been energized with currents up to 100A (corresponding to a maximum value of 7 Tesla). Regarding the cryostat, before the end of the year begins the reassembling of the system to make possible vacuum tests and later operations at low temperature.

3 Operation on the PRESS-MAG-O insert

We proceeded also the final commissioning of the PRESS-MAG-O insert. The heart of the system is a SQUID gradiometer designed and manufactured to operate inside the Diamond Anvil Cell (DAC) with a SQUID amplifier placed on the bottom of the insert. Several measurements have been performed to test the gradiometer operation at 4.2 K with a superconducting sample (a YBCO sample of dimension $\sim$0.16 mm^3) loaded in the DAC cell. To remove noises due to the interferences of RF signals we shielded the SQUID signals with a box made by ferrite RF filters and capacitors (see fig.1 left).

Different measurements have been performed to set the procedure and the suitable experimental set-up for ac susceptibility multi harmonic experiments using the instrumental chain formed by a Sinusoidal Pulse Amplifier and an AC Current Amplifier to control the magnetic field excitation and the SQUID-gradiometer, the Lock-In amplifier to measure the magnetic signal of the superconducting coils sets inside the DAC cell. The procedure optimizes: **1)** The functionality of the SQUID maximizing the response with a signal test generated by the SQUID system. At first

we use a sinusoidal test signal of 6mV at 107Hz corresponding to ∼12 mGauss that give a pick-up signal of 15 flux quanta (see fig. 1, rigth panel). **2)** The ac exciting magnetic field starting with an amplitude of 12.8 mV corresponding to 25.6 mGauss at 107 Hz frequency to test the linear response of the SQUID. **3)** The Lock-In amplifier has measured the signals of the first and third harmonics of the SQUID that pick-ups the superconducting gradiometer at 4.2 K, 107Hz and 25.6 mGauss. We carried out also measurements at different values of the frequency (17-1070 Hz) and of the ac magnetic fields (10 mGauss-10 Gauss) always at 4.2 K. The SQUID-gradiometer showed a high sensitivity working at magnetic fields excitation of the order of mGauss. For magnetic fields greather then 1 Gauss attenuators have to be inserted to probe the magnetic response with the Lock-In amplifier.

Figure 1: *(left) The RF filter box of the SQUID connector; (right) SQUID test performed at* $4.2K$ *with an a.c. magnetic field of* $0.012G$ *at* $107Hz$. 15*fluxons quanta have been measured*

4 Experimental activity

In additions to the commissioning of the PRESS-MAG-O instruments, we continued in the LAMPS-LNF laboratory to perform experiments on highly correlated materials. In this context, we contributed with our magnetic susceptibility measurements to publish an important research within an international collaboration between the *Laboratori Nazionali di Frascati* of the INFN, the London Centre for Nanotechnology (LCN), the Rome International Center for Materials Science RICMASS, and the *Sapienza* University on the Proceedings of the National Academy of Sciences (USA).The breakthrough we discussed in this contribution is that the competition between networks drive these materials to an optimum inhomogeneity made of a complex scale free distribution similar to the competition between two networks of social relations. We show that is the organization of two types of defects in the La_2CuO_{4-y}, that determines the superconductivity at high temperature in a ceramic superconductor. The first defects are the additional oxygen atoms that are introduced in a simple parent oxide of copper to induce superconductivity, while the second network is made of deviations of atoms from where they would have been in the parent material (see Fig. 2 Right). At Frascati we measured the components of the multi-harmonic ac susceptibility that probes the different phases superconducting controlled by thermal processes (see fig. 2 Left). This results has been also presented as a NEWS on the INFN webpage on October 8, 2012.

We also continued flux dynamic studies on 1111 and 11 iron-based superconductors such as $NdFeAsO_{0.86}F_{0.14}$ and iron chalcogenide superconductors. AC multi-harmonic susceptibility measurements have been performed and the analisys have been performed in the glass-weak pinning scenario. In particular, the comparison of the third harmonic components vs. temperature under a magnetic field returned information on pinning strength and dimensionality. We showed that in some HTS systems, although in the presence of large thermal fluctuations, an increase of the

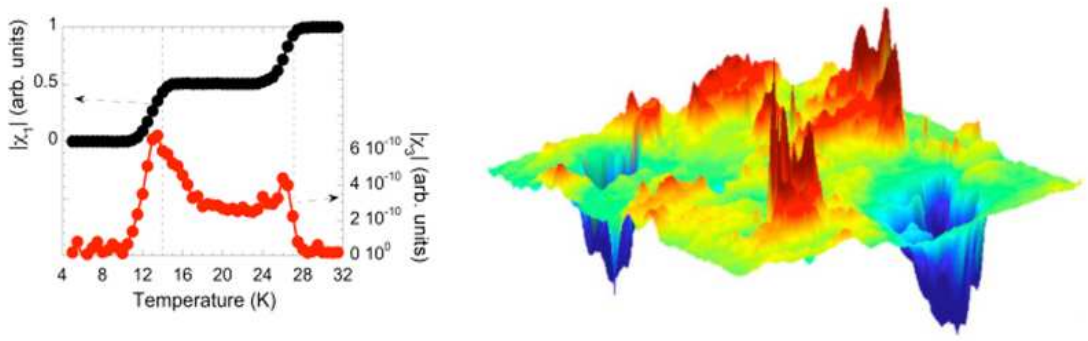

Figure 2: *Right: the first harmonic (real part),* χ_1'*, and the modulus of the ac susceptibility third harmonic,* χ_3*, of the underdoped* $La_2CuO_{4.06}$ *showing two transitions at* $14K$ *and* $\sim 27K$*. Left: the three dimensional color plot imaging the position dependence of the Q3-LLD superstructure intensity I(Q3)/*I_0 *(values>*0*) and of the Q2-Oi superstructure intensity I(Q2)/*I_0 *(values<*0*) (from PNAS 109, (39) (2012) pp. 15685-15690)*

pinning amplitude is observed. The phenomenon is particularly evident in the 1111 Fe-based superconductor systems where a spacer layer among superconducting planes exists (see fig.3).

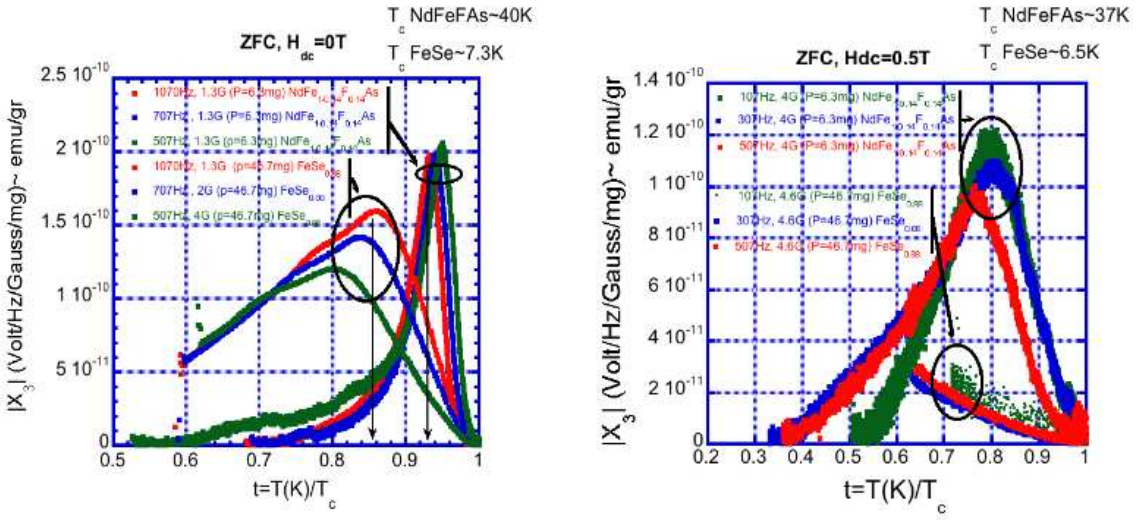

Figure 3: *Comparison of the* χ_3 *module vs. reduced temperature t at different frequencies for* $NdFeAsO_{0.86}F_{0.14}$ *and* $FeSe_{0.88}$*, Left:* H_{dc}=$0\,T$ *, Right:* H_{dc}=$0.5\,T$*. The black arrows pointing the t axes indicating the different t values for two samples*

5 International collaboration

In 2012 within the Executive Programme of Scientific and Technological Cooperation between Italian Republic and the Republic of India for the years 2012 2014 was funded by the Italian Minister of Foreign Affair a bilateral project to the INFN-LNF. From the Italian side is coordinated by A. Marcelli and the cooperation is established with the Institute of Plasma Research (IPR) in Gandhinagar coordinated by C. Balubramanian. The project is dedicated to the investigation of local structure and magnetism of Co nano-structures. In 2012 we hosted Indian researchers and started the experimental activities in the LAMPS-LNF laboratory. Some preliminary experimental data are shown in Fig. 4

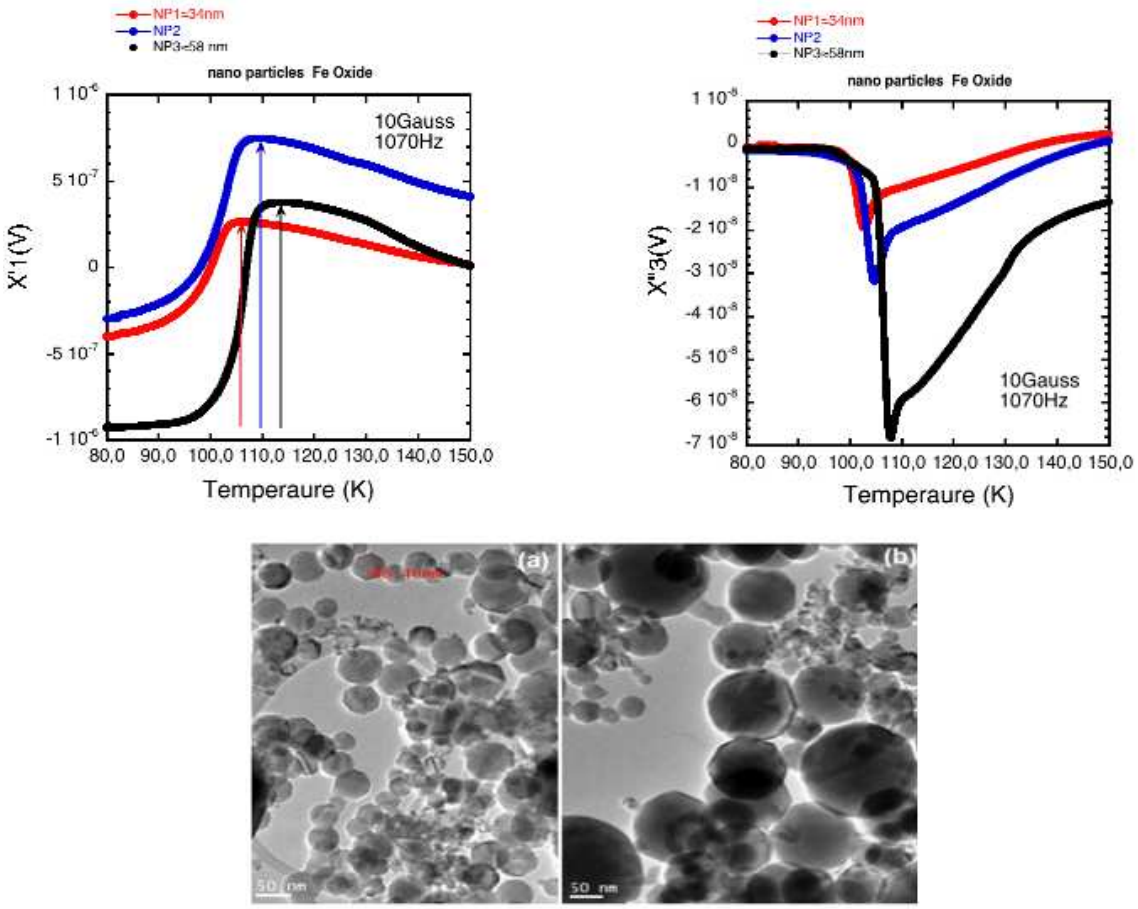

Figure 4: *Up: AC susceptibility first harmonic real part, χ'_1, and third harmonic imaginary part, $\chi"_3$, vs. temperature for different Fe-oxide nano-particles. Down: TEM micrographs of the nano-particle samples dimension. (a) and (b) are respectively samples prepared under conditions 32 Ampere (d∼34nm) and 65 Ampere (d∼58nm)*

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6 Thesis and PhD

At the laboratory, "LAMPS" in INFN-LNF (Frascati) were carried out the following theses:

1) Dr. Alessandro Puri PhD XXIV Materials Science Universit Sapienza Rome, title: Experiments on strongly correlated materials under extreme conditions, 2009/2012.
Supervisors: Dr. D. Di Gioacchino, Dr. A. Marcelli , Prof. Naurang Saini.
After obtaining the doctorate, dr. A. Puri is doing a two-year contract at the Faculty of Sciences Radboud University in European Magnetic Field Laboratory - EMFL Project-High Field Magnet Laboratory - Nijmegen (Netherlands).

2) Buerhan Shalamu, Degree thesis in the Structure of Matter, University of Camerino, title: Vortex dynamics in the HTSC iron pnictide $SmFeAsO_{0.85}F_{0.15}$, 2012/2013
Supervisors: Dr. D. Di Gioacchino, Dr. A. Marcelli , Prof. Roberto Gunnella.

3) Kamili Yimamu, Degree thesis in the Structure of Matter, University of Camerino,title: Characterization of carbon based resistive patterns on synthetic diamond plates for microdevice design, 2011/2012
Supervisors: Dr. A. Marcelli, Dr. D. Di Gioacchino, Prof. Roberto Gunnella.

7 Oral contribution

1) D. Di Gioacchino, "Flux dynamics in Iron-based superconductors" *Applied Superconductivity Conference 2012, 7-12 October 2012 Portland, (Oregon)*
2) A. Puri, "Evidence of 3D 2D transition in the magneto flux dynamic of $NdFeAsO_{1-0.14}F_{0.14}$" *SuperFOx-2012, First Conference on Superconductivity and Functional Oxides, Como (Italy), 19-22 June 2012*

8 Acknowledgements

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References

1. D. Di Gioacchino A. Puri, A. Marcelli, N.L. Saini, *Flux dynamics in Iron-Based Superconductors* , IEEE Transaction on Applied Superconductivity, in press

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3. Poccia, N., Ricci, A., Campi, G., Fratini, M., Puri, A., Di Gioacchino, D., Marcelli, A., Bianconi, A. *Optimum inhomogeneity of local lattice distortions in* La_2CuO_{4+y} , Proceedings of the National Academy of Sciences of the United States of America 109 (39) (2012) pp. 15685-15690)