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THE INVESTIGATION OF HIGH TEMPERATURE SUPERCONDUCTORS AT THE JOINT INSTITUTE FOR NUCLEAR RESEARCH

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This is a brief review of the performed at the JINR investigations in the field of high-temperature superconductivity physics and experimental methods exploited.

The investigation has been performed at the Laboratory of Neutron Physics, JINR.

Исследования высокотемпературных сверхпроводников в Объединенном институте ядерных исследований

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Дан краткий обзор проводимых в ОИЯИ исследований в области высокотемпературной сверхпроводимости и используемых экспериментальных методик.

Работа выполнена в Лаборатории нейтронной физики ОИЯИ.

The JINR program on high temperature superconductors (HTSC) in which all the Laboratories take part outlines five directions of investigation: the theory of mechanisms of superconductivity, the structure and dynamics of the lattice of HTSC, magnetic properties, the influence of irradiation on the HTSC properties, the development of SQUIDs and magnetometers on their base.

Theoretical studies are under way in the direction of the consequent consideration of strong electronic correlations /1, 2/ and strong anharmonic quasi-local lattice vibrations /3-6/ by the method suggested by N.N.Bogolubov in 1949 for the study of the polar model of metal (the Shubin-Wonsowsky model) and using the model description of the structural instability effect on superconducting pairing developed at Dubna at the end of the 70's — beginning 80's. Besides, the thermodynamic and dynamic properties of the superconducting glassy state characteristic for new superconductors are studied /7/. The first four papers of the Rapid Communications report on the result.

The experimental part of the program is determined essentially by the experimental apparatuses and nuclear physics methods developed at the JINR for the condensed matter research. First of all, this is particularly true for *the neutron scattering method.* The experiments which exploit such method are carried out at the Laboratory of Neutron Physics at the pulsed reactor IBR-2.

The IBR-2 reactor is one of the most advanced high flux reactors in the world. Its peak flux of thermal neutrons at the moderator surface is 10^{16} n cm^{-2} s^{-1}. At present there are no other neutron sources of such kind for scientific research in the USSR. In the nearest decade the reactor units and systems will be improved in order to increase the reactor mean power by 1.5 times, and reduce the reactor pulse in half, and obtain the thermal neutron flux of more than 10^{16} n cm^{-2} s^{-1}.

The HTSC investigations at the IBR-2 started in October, 1987. At that time the scientists got the possibility of using the reactor to conduct experiments after the planned replacement of the moving reflector. The first experiments were performed with lanthanum ceramics synthesized at the Baikov Institute of Metallurgy of the USSR Academy of Sciences. The inelastic incoherent neutron scattering spectra were measured at the KDSOG-M spectrometer on undopped and dopped by Sr (20 p.c.) lanthanum cuprate at temperatures of 10, 77 and 290 K. A new peak of the magnetic nature at about 6 meV was observed [8] at temperature below 290 K. Further experiments on samples with a strontium concentration of 10 and 30 p.c. confirm these results. The intensity of this peak increases with decreasing temperature and decreases with increasing strontium concentration. After the experiments have been accomplished the chemical composition was checked by neutron activation analysis, showing the amount of impurities (besides of Sr) below 0.5 p.c. Thus, the observed magnetic scattering seems to be intrinsic, possibly, due to short-order antiferromagnetic clusters.

The measurements on yttrium ceramics with different oxygen contents at temperatures between 10 and 290 K showed the appearance of additional magnetic scattering in the energy range from 15 to 40 meV of as yet unclear origin. These experiments were performed in collaboration with the Solid State Physics Institute of the USSR Academy of Sciences. The results are under preparation and will be published elsewhere.

The main advantage of the spectrometer KDSOG-M, i.e. the possibility of investigating the excitation spectrum at low temperatures and low transfer energies, was used in these experiments. Besides, the original property of the spectrometer is the fact that the spectrometer allows the simultaneous measurements of inelastic and quasielastic scattering. At present the mean thermal neutron flux on a sample, mounted in the spectrometer KDSOG-M is about 10^7 n $cm^{-2}s^{-1}$at a time resolution reaching 1 p.c. A higher resolution spectrometer, NERA-PR, the construction of which is nearly accomplished, will improve significantly the possibilities of measurements.

Interesting results were obtained at studying of the structure of the yttrium ceramics manufactured at the Moscow State University under changing oxygen content. Besides obtaining more detailed data on the structural phase transition, the existence of antiferromagnetic ordering at the oxygen content $x < 6.2$ was confirmed in these experiments. These results are presented in this issue of Rapid Communications. Other results of yttrium ceramics with iron substitution of copper and on bismuth ceramics are under preparation for the publication elsewhere. The measurements were performed with the diffractometer DN-2.

The DN-2 diffractometer permits the effective use of the wide spectrum of neutron wavelengths. This fact determines its advantages over the diffractometers at the stationary reactors in investigations requiring the detection of a great number of points of reciprocal space at low and middle momentum transfers and the high flux of neutrons at moderate resolution as well. The neutron flux on a sample is about $8x10^6$ n $cm^{-2}s^{-1}$; a wavelength range, from 1.2 to 25 Å; and the interplanar spacing, from 0.6 to 120 Å, the resolution $\Delta d/d$ reaches 1 p.c. The diffractometer DN-2 may be efficiently used for the investigation of long-period structures ("new" bismuth compounds belong to this class also), superstructures, twins, domains and phase mixtures as well. The mentioned diffractometer is in fact the only one in the USSR, which can be used for the study of long-period structures in monocrystals.

At present the new diffractometer of high resolution (up to 0.05%), "super-SFINKS", is under construction at the IBR-2. This project is realized together with the Leningrad Institute of Nuclear Physics of the USSR Academy of Sciences (Gatchina) and the Reactor Laboratory of the Technical Centre in Finland. This project is the development of the "maxi-SFINKS" project for the high flux reactor "PIK", which is being constructed in Gatchina. It has undergone successful approbation as the "mini-SFINKS" diffractometer which is today under operation in Gatchina.

Besides the investigations mentioned above, test experiments were performed at the MURN spectrometer by the small-angle scattering method, and at the SPN-1 spectrometer by using polarized neutrons.

The method of spin relaxation of muons being developed at the Laboratory of Nuclear Problems for 15 years, gives unique possibilities for the study of magnetic properties of new superconductors on the microscopic level. The time spectrum of positrons from the positive muons decayed in matter is being measured during these experiments. Experimental data give information on the volume of superconducting phase in a sample, on the mean local magnetic field acting on a muon, on the magnetic field penetration depth and on the magnetic field distribution in vortices. Experiments carried out under various conditions, e.g. on a zero magnetic field cooled sample and on a magnetic field cooled sample with the following change of external parameters, present a more complete picture of new superconductors' behaviour in studies of a glassy state in particular.

The experiments on the study of the HTSC properties at the phasotron of the Laboratory of Nuclear Problems began last summer in collaboration with the Kurchatov Institute of Atomic Energy. Before that time, first measurements were conducted at the synchrocyclotron of the Leningrad Institute of Nuclear Physics (USSR AS) by a group of scientiscs of the Institute, the Kurchatov Institute and the Laboratiry of Nuclear Problems (JINR). This group of scientists was one of the first groups in the world applying the muon method to the study of the HTSC [9,10]. The results on the depth of magnetic field penetrating the sample and the existence of the superconductive glass phase are the most important ones.

The experiments are being carried out at the MUSPIN installation which has the muon beam intensity of $3x10^5$ muon/μA with a momentum of 130 MeV/s and the beam polarization near to 80%. The counting rate of decay events with a target of 40 mm in diameter is $3x10^3$ s^{-1}. The installation at the Leningrad Institute of Nuclear Physics has parameters near to those mentioned above. The measurements at the MUSPIN installation are being carried out at external fields (longitudinal and transverse) up to 0.7 T in the temperature range from 4.2 to 300 K. Further this interval is to be extended to the low temperature range.

This collection reports also on the work carried out at the Laboratory of Nuclear Problems by use of *positron annihilation.* Being the source of important information on the Fermi surface, this method will be further developed.

The JINR has unique possibilities for conducting investigations connected with the influence of *accelerated particle irradiation* on the HTSC physical properties. The main installation of the High Energy Physics Laboratory, the synchrophasotron with a proton energy of 9 GeV and the electrostatic generator of the Laboratory of Neutron Physics with a proton energy of 4 MeV may be used for irradiation, besides the mentioned phasotron for the proton acceleration to an energy of 680 MeV. The particle fluxes per cm^2/ hour are from 10^{15} to 10^{17} with a particle range in the medium from 10 to 10^4 μm. Some nuclei with energies up to 4 GeV per nucleon and a fluence from 10^6 to 10^{14} and a particle range above 10^4 um are being accelerated in the synchrophasotron as well. The accelerators of the Laboratory of Neutron Physics, the Laboratory of Nuclear Reactions and of the Institute Scientific Methodical Department (ISMD) produce the electrons with an energy from 2 to 40 MeV and a fluence of 10^{18}, a particle range being from 10^2 to 10^4 μm. The cyclotrons of the Laboratory of Nuclear Reactions used for the acceleration of ions with an atomic number from 2 to 84, with an energy from 1 to 20 MeV per nucleon and a fluence from 10^{13} to 10^{18}, and a particle range in medium from 3 to 100 μm have rather important potentialities. The first results of work at the synchrophasotron and at the installation of ISMD are presented in this collection. On the whole, it should be noted that this direction, important for further practical applications of the HTSC, is still the direction of unutilized potentialities.

A rather well developed cryogenic base of the JINR permits the conduction of *thermodynamic and electromagnetic investigations* necessary for the sample testing. Some results are presented here as well. Experience on conducting precision measurements enabled the scientists of the Laboratory of Neutron Physics to perform a very sensitive experiment on the study of the effect of the isotopic copper substitution on the temperature of the superconducting transition in yttrium ceramics /11/. Recently, the SQUID from yttrium ceramics working at liquid nitrogen temperature with sensitivity approximately equal to that of ordinary SQUIDs working at helium temperature, was manufactured at the Laboratory. The application of such SQUIDs is as yet delayed for the lack of conducting materials from HTSC.

In conclusion I would like to express hope that this compressed review of the JINR facilities and of some recent results /1-14/ together with other papers entering the given Rapid Communications will give its readers the idea of the JINR possibilities of investigation in the field of high temperature superconductivity and will promote to further scientific cooperation between the JINR Member States in this important branch of modern physics.

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