HIGH T_c UPDATE

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NOTA BENE:

$Na_{0.05}WO_3$

A recent preprint by S. Reich and Y. Tsabba (Weizmann Institute) reported experimental evidence suggesting the possibility of superconductivity with $T_c \approx 91$ K in WO_3 crystals with a surface composition of $Na_{0.05}WO_3$. (For further details, see Nota Bene and the preprint listing in the May 1 issue of High-T_c Update.) A. Shengelaya and K. A. Müller (Zürich) now have joined with Reich and Tsabba to carry out electron-spin-resonance (ESR) measurements on samples of WO_3 doped with *Na*. According to a new preprint, the authors detected an ESR signal with unresolved fine and/or hyperfine structure, and they used the saturation method to determine the spin-lattice relaxation rate $1/T_1$ of these paramagnetic centers. Upon cooling below about 100 K, $1/T_1$ decreased markedly with decreasing temperature. Except for the absence of a Hebel-Slichter peak, the results resemble NMR $1/T_1$ measurements when a gap opens in the superconducting state. Below about $T = 0.6\ T_c$, where T_c is assumed to be 91 K, the authors found that $1/T_1 \propto \exp(-\Delta/k_B T_c)$ with a gap parameter $\Delta = 160$ K or $2\Delta/k_B T_c = 3.5$, in good agreement with the weak-coupling BCS theory. The authors emphasize that for $YBa_2Cu_3O_{7-\delta}$ compounds, no ESR such as that reported here is known, thus excluding possible contamination of the WO_3:*Na* samples by *YBCO* as the origin of the superconducting signatures with a T_c of 91 K.

The authors also report temperature-dependent field-cooled (FC) and zero-field-cooled (ZFC) dc susceptibility data obtained with a SQUID magnetometer. The two curves differ strongly below T_c, with the FC magnetization lying above the ZFC magnetization. In contrast to the cuprate superconductors, the parent compound WO_3 is nonmagnetic, indicating that when WO_3 is doped with *Na,* antiferromagnetism could not be responsible for either the magnetization hysteresis or the high T_c. The authors interpret all their results as suggesting a 91 K transition from a semiconducting to a nonpercolating 2D superconducting state on the surface of an insulator (a bulk WO_3 crystal) when the surface is doped with sodium.

$RBa_2Cu_3O_{7-\delta}$

According to a preprint by D. Mihailovic et al. (Ljubljana), a systematic quantitative comparison of pseudogap values obtained from an analysis of charge- and spin-excitation spectroscopies in underdoped $YBa_2Cu_3O_{7-\delta}$ using a temperature-independent gap shows two distinct excitations, one (Δ_S) visible in spin-flip spectroscopies such as NMR and spin-polarized neutron scattering, and the other (Δ_p) revealed in charge-excitation spectroscopies such as single-particle tunneling and time-resolved quasiparticle relaxation. Both Δ_S and Δ_p appear to decrease with doping x approximately as 1/x and are T-independent, existing both above and below T_c. The authors suggest that the spin excitation can be explained by an intragap local triplet state, while the charge excitation can be attributed to a pair-breaking local gap.

The *Pr* concentration dependence of the superconducting transition temperature T_c in the $Ho_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ system has been determined by Z. Tomkowicz (Krakow) via measurements of the dc electrical resistance. Both this system and $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ have the same value of the critical concentration $x_c = 0.58$, in accordance with the nearly equal ionic radii of Ho^{3+} and Y^{3+}. The author finds that the $T_c(x)$ curve can be described with a single mechanism based on a decreasing number of sheet holes trapped by Pr^{IV} ions, provided one takes into account that the number of these ions changes with x.

From magneto-optical imaging performed on heavy-ion-irradiated $YBa_2Cu_3O_{7-\delta}$ single crystals, M. V. Indenbom (Chernogolovka and Ecole Polytechnique) et al. have found that at fields and temperatures where strong single vortex pinning by individual irradiation-induced amorphous columnar defects is to be expected, vortex motion is limited by the nucleation of vortex kinks at the specimen surface rather than by half-loop nucleation in the bulk. Deep in the material, vortex motion occurs through easy kink sliding, irrespective of the relative alignment between vortex lines and ion tracks.

The effects of adding insulating *211* particles *[(Nd_x $Eu_x$$Gd_{1-2x})_2BaCuO_5$* or *NEG-211]* into melt-textured *123* superconductors of the type *($Nd_{0.33}Eu_{0.33}Gd_{0.33}$)-$Ba_2Cu_3O_{7-\delta}$ (NEG-123)* have been studied by M. Muralidhar et al. (SRL-ISTEC). The authors found that the position of the secondary peak in J_c vs B can be shifted to higher values of B by increasing the *Gd* content within the *211* particles, but the largest J_c at the peak was achieved with x = 0.33.

Bi Cuprates

The interlayer phase coherence in *$Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212)* has been quantitatively determined over a wide field range by T. Shibauchi et al. (Tokyo) using the Josephson plasma resonance. At the first-order-transition (FOT) line, the authors found a frequency-independent Josephson plasma resonance with a narrow width, indicating that the interlayer phase coherence abruptly changes at the FOT. Above the FOT line, sample-moving magnetization measurements showed an anomaly similar to the new phase boundary reported by D. T. Fuchs et al. [Phys. Rev. Lett. **80**, 4974 (1998)], but the interlayer phase coherence showed no anomaly. These results indicate the decoupling nature of the FOT and rule out a vortex line-liquid state over the fields investigated.

By sweeping the microwave frequency continuously, M. B. Gaifullin (Tokyo) et al. have measured the Josephson plasma resonance for underdoped *$Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi-2212)* and *$Bi_2Sr_2CuO_6$ (Bi-2201).* The authors determined the superfluid density and the quasiparticle conductivity σ_c^{qp} along the c axis from measurements of the resonance frequency and line width. In slightly underdoped crystals, the superfluid density shows very little change at low temperatures, a result consistent with a d-wave coherent-tunneling model. In the strongly underdoped crystals, σ_c^{qp} falls to low values below T_c but then decreases only gradually with decreasing T, a behavior very different from that in the ab plane.

Measurements of the in-plane and out-of-plane resistivities ρ_{ab} and ρ_c vs temperature in the fluctuation-conductivity range above T_c have been carried out by C. Boulesteix (Marseille) et al. on different kinds of as-grown *Bi-2212* crystals. For weakly oxidized (underdoped) crystals, 2D fluctuations occur over a large temperature range, while for highly oxidized crystals (with a metallic out-of-plane conductivity), 3D fluctuations occur over a large temperature range.

The position of *Dy* dopant atoms in the unit cell of *Bi-2212* has been determined by P. Shang (Birmingham) et al. using direct-space chemical crystallography (EDX). The authors stress that such methods of determining sublattice occupancy are favored over classical x-ray diffraction methods as the number of components rises.

Results related to the use of the PAIR process (pre-annealing and intermediate rolling) for the fabrication of *Bi-2212/Ag* tapes are presented in three preprints listed in this issue. H. Miao (NRIM and CREST, Tsukuba) et al. report the optimal melt-processing temperature schedule to achieve high J_c values of 4.0×10^5 A/cm^2 at 4.2 K in a 10 T field parallel to the tape surface. H. Kitaguchi (NRIM) et al. report studies of the dependence of J_c upon the *Bi-2212* thickness. The authors attribute the success of the PAIR process to improvements in the macroscopic homogeneity of the *Bi-2212* layer. A second paper by H. Kitaguchi (NRIM) et al. reports on the J_c performance of PAIR-processed tapes in the temperature range 10-50 K.

Other Cuprates

An NMR-pulse double-irradiation method that allows the separation of magnetic and quadrupolar contributions to the spin-lattice relaxation has been developed by A. Suter et al. (Zürich). The pulse sequence fully saturates one transition while another is observed. The method is especially useful when only one NMR-sensitive isotope is available. A second preprint by A. Suter et al. (Zürich) describes the application of this method to carry out an *^{17}O* NMR study in the stoichiometric superconductor *$YBa_2Cu_4O_8$*. The authors find that below 180 K, the spin-lattice relaxation rate of plane oxygens is driven not only by magnetic fluctuations but also by quadrupolar fluctuations, i.e., low-frequency charge fluctuations. In the superconducting state, as the temperature is lowered, the quadrupolar relaxation diminishes faster than the magnetic relaxation. These results show that, with the opening of the pseudo spin gap, a charge degree of freedom of mainly oxygen character is present in the electronic low-energy excitation spectrum.

Inelastic neutron scattering has been used by B. Lake (Toronto, Oak Ridge, and Risø) et al. [Nature **400**, 43 (1999)] to determine the wavevector dependence of spin pairing in superconducting *$La_{2-x}Sr_xCuO_4$*. The authors found that the spin pairing energy (spin gap) is wavevector independent, even though superconductivity significantly alters the wavevector dependence of the spin fluctuations at higher energies. These measurements, which are sensitive only to the spin sector, taken together with the evidence for d-wave superconductivity in the charge sector, suggest that the high-T_c superconductors are Luther-Emery liquids: materials with gapped (triplet) spin excitations and gapless spin-zero charge excitations.

Local structural evidence supporting the presence of charge inhomogeneities in the *CuO_2* planes of underdoped *$La_{2-x}Sr_xCuO_4$* are presented in a paper by E. S. Bozin (Michigan State) et al. High-resolution atomic pair distribution functions (PDFs) were obtained from neutron powder diffraction data over the range of doping $0 \le x \le 0.30$ at 10 K.

As x increases, although the average structure becomes less orthorhombic, the authors find a broadening of the in-plane *Cu-O* bond distribution up to optimal doping, but thereafter the peak abruptly sharpens. Complementary evidence also comes from the observation of octahedral tilt disorder in the PDF at higher atomic separation. This suggests a crossover from a charge-inhomogeneous state below optimal doping to a homogeneous charge state above optimal doping.

A preprint by I. M. Abu-Shiekah (Leiden) et al. reports a study of stripe fluctuations in $La_2NiO_{4.17}$ by ^{139}La NMR using the field and temperature dependence of the linewidth and relaxation rates. The authors find strong similarities in slow stripe fluctuations between *Sr*-doped cuprates $(La_{2-x}Sr_xCuO_4)$ and oxygen-doped nickelates. In the formation process of the stripes in $La_2NiO_{4.17}$, the NMR line intensity is maximal below 230 K, starts to diminish around 140 K, disappears around 50 K, and recovers at 4 K, below which the stripes become static. The authors show that these results are consistent with but completely complementary to neutron measurements, and that they are generic for oxygen-doped nickelates and underdoped cuprates.

Tunneling spectra and the superconducting gap in *Bi-2212* and $Tl_2Ba_2CuO_{6+\delta}$ *(Tl-2201)* are reported by L. Ozyuzer (Argonne and IIT) et al. Using superconductor/insulator/superconductor (SIS) break junctions, the authors investigated the tunneling spectra in *Bi-2212* over a wide doping range and found that the energy gap displays a monotonic dependence on doping, increasing to large values in the underdoped region even as T_c decreases. This leads to unphysically large values of the ratio $2\Delta/k_BT_c \sim 20$. Each spectrum exhibits dip and hump features at high bias with characteristic energies that scale with the superconducting gap. The tunneling spectra of near optimally doped *Tl-2201* also display a weak dip feature in superconductor/insulator/normal-metal (SIN) junctions. The authors conclude that dip and hump features in SIS junctions are generic to high-temperature superconductors.

After examining recent tunneling data on hole-doped cuprates, A. Mourachkine (Brussels) concludes that there are two superconducting order parameters: one (Δ_c) for Cooper pairing and the other (Δ_p) for phase coherence.

Films

The use of quasiparticle planar tunneling spectroscopy to investigate the density of states in $YBa_2Cu_3O_{7-\delta}$ is described by L. H. Greene (UIUC) et al. The dependencies upon temperature, crystallographic orientation, doping, damage, and magnetic field confirm that the observed zero-bias conductance peak (ZBCP) is an Andreev bound state, an intrinsic property of a d-wave superconducting order parameter at an interface. In zero applied field, the splitting of the ZBCP below ~8 K confirms a near-surface phase transition into a superconducting state with spontaneously broken time-reversal symmetry. Tunneling into the Andreev bound state provides a phase-sensitive spectroscopy that can be used to measure a variety of properties of the density of states in an unconventional superconductor.

A systematic study of texturing mechanisms in pure *Ag* is presented in a preprint by H. Suo (Geneva and Beijing Polytechnic) et al., the goal being to obtain a cube-textured {100}<001> tape that can be used as a substrate for superconducting coated conductors. The authors report details of how a sharp cube texture can be produced after preheated deformation and recrystallization. The stability of the cube texture at high temperatures up to 900°C indicates that the tapes are suitable for epitaxial growth of superconducting oxides.

As reported by A. Wang et al. (Northwestern), smooth, epitaxial cerium dioxide (CeO_2) thin films have been grown *in-situ* in the 450-650°C temperature range on (001) yttria-stabilized zirconia *(YSZ)* substrates by metal-organic chemical vapor deposition (MOCVD) using a fluorine-free liquid *Ce* precursor. As assessed by x-ray diffraction, transmission electron microscopy (TEM), and high-resolution electron microscopy (HREM), the epitaxial films exhibited a columnar microstructure with atomically abrupt film-substrate interfaces and with only minor bending of the crystal plane parallel to the substrate near the interface and at the column boundaries. With fixed precursor temperature and gas flow rate, the CeO_2 growth rate decreased from ~10 Å/min at 450°C to ~6.5 Å/min at 540°C. The root-mean-square roughness of the films also decreased from 15.5 Å at 450°C to 4.3 Å at 540°C. High-quality, epitaxial $YBa_2Cu_3O_{7-\delta}$ films were deposited on these CeO_2 films via pulsed organometallic beam epitaxy (POMBE); they exhibited $T_c = 86.5$ K and self-field $J_c = 1.08 \times 10^6$ A/cm^2 at 77.4 K.

A preprint by E. V. Pechen (Lebedev Institute) reports that a special shaping of the $YAG:Nd^{3+}$ laser beam profile can improve homogeneity and T_c of pulsed-laser-deposited (PLD) $YBa_2Cu_3O_{7-\delta}$ films. Targets of nonstoichiometric composition and substrates with slanting cuts were found to be necessary for high-quality film growth. The author found that multiple droplets and solid particles ejected from the target surface by infrared radiation could be removed from the laser-induced plasma by use of a velocity filter (disk-chopper).

The resistive transition of $(YBCO)_{24}/(PBCO)_2$ multilayer thin films has been measured by X. W. Cao (Hefei) et al. as a function of temperature and the angle θ between the CuO_2 planes and the 4 T applied magnetic field. The angular dependence of the characteristic temperature T* was found to exhibit either 2D or 3D behavior. The data also revealed a lock-in transition at a critical angle θ_c of about 13°.

Applications

High-T_C current leads for electrical connection to low-T_C superconducting magnet coils are attractive because the high-T_C oxides have a low thermal conductivity at temperatures below their T_C, thus allowing the length of the current leads to be reduced. A preprint by X. K. Fu et al. (Wollongong) reports that a new method using a combination of cold isostatic pressing (CIP) and hot pressing (HP) has been applied to fabricate *Bi-2223* bar current leads. The critical current density achieved by this method reached as high as 10^3 A/cm^2 at 77 K in self-field.

Vortices

The vortex-lattice melting transition in magnetic fields parallel to the ab planes has been studied by Yu. Eltsev (KTH-Stockholm and SRL-ISTEC) and Ö. Rapp (KTH-Stockholm) in twinned $YBa_2Cu_3O_{7-\delta}$ single crystals using transport measurements along the c axis. In contrast to a previously studied geometry with both field and current parallel to the planes [W. K. Kwok et al., Phys. Rev. Lett. **72**, 1088 (1994)], the present authors found a step-like c-axis resistive transition for exact field alignment along the ab planes. The authors also studied the angular dependence of ρ_C with rotation of the crystal around the c axis. The results show that below the resistive step, the pinning force is anomalously increased when the field is aligned along ac or bc crystal facets, indicating strong surface-pinning effects.

Vortex-lattice melting and depinning have been studied theoretically by J. P. Rodriguez (California State, Los Angeles) using the uniformly frustrated layered XY model in its Villain form. The author identified a decoupled pancake vortex liquid phase, which is bounded by both first-order and second-order decoupling lines in the magnetic field vs temperature (H vs T) plane. These transitions, respectively, account for the vortex-lattice melting and vortex-lattice depinning behavior observed in the mixed state of clean high-temperature superconductors.

Using realistic London Langevin computer simulations with parameters corresponding roughly to *YBCO,* C. J. Olson et al. (UC-Davis) have found an enhancement of the critical current when artificial columnar defects are introduced in a splayed configuration. When vortex entanglement is not present, the improvement in transport properties appears only for regimes of vortex creep when the splay angle is sufficiently small, and the improvement then results from the suppression of kink propagation. At higher applied currents, the resistivity in the splayed sample becomes as large as that in a sample with parallel columnar pins. The authors find that the best angle for splay is related to the accommodation angle of the columnar pins; the highest J_C was found for transverse bimodal splay angles $\theta \approx \pm 10^\circ$.

A preprint by A. W. Smith (Chicago) et al. reports measurements of the onsets of a resistive response and transverse flux penetration in the Bose-glass phase in an untwinned $YBa_2Cu_3O_{7-\delta}$ single crystal containing columnar defects along the c axis. The resistive onset was measured using an ac technique with a pickup coil placed near the sample, while the onset of a local magnetic field component perpendicular to the columnar defects was probed using a micron-sized *InAs* Hall-probe array. Even for tilt angles as small as one degree, the two measurements yielded strikingly different demarcations for the Bose-glass phase. The authors suggest that a new intermediate regime exists between the glass and the liquid state which exhibits no vortex flow even in the absence of a fully developed transverse Meissner effect, and they stress that these results evidently are in conflict with the current theoretical framework for two-dimensional bosonic states, which allows for only a single transition.

A preprint by A. P. Hope (SUNY-Buffalo) et al. reports observations in superconducting single-crystal $YBa_2Cu_3O_{7-\delta}$ of a series of avalanche-like flux jumps, seen as a saw-tooth pattern in the torque vs sample orientation in a magnetic field. While reminiscent of the classical flux jump instability, the present discontinuous jumps are proposed to be associated with the layered nature of the material and twin-boundary pinning, the combination of which promotes a crossover from a tilted to a kinked vortex structure.

Simulations of vortex avalanches in the critical state of a type-II superconductor with periodic pinning have been carried out by R. Cruz et al. (Havana). The authors found that the results could be scaled, and they extracted numerical values of the resulting critical exponents. The authors report that they have found a new universality class for strong and dense periodic distributions of pinning centers.

Investigations of quasi-Josephson effects due to coherent vortex motion in artificial reversible periodic pinning potential structures in $YBa_2Cu_3O_{7-\delta}$ thin films have been carried out by Y. Yuzhelevski (Ben Gurion University of the Negev) et al. To produce periodic pinning conditions, a magnetic tape containing a prerecorded harmonic signal was placed on the surface of the superconducting thin film. The authors found that current-driven motion of Abrikosov vortices in wide and short macrobridges of this film led to the appearance of Josephson-like effects, manifested as a series of self-induced current steps on the current-voltage characteristics.

Abrikosov and Josephson vortices trapped in bicrystalline $YBa_2Cu_3O_{7-\delta}$ washer-type dc SQUIDs containing regular arrays of micrometer holes (antidots) have been directly imaged by S. Keil (Tübingen) et al. using a standard electron microscope equipped with a liquid-nitrogen-temperature cryostage. Signal generation is based on the electron-beam-induced local vortex displacement, which is detected as a flux change in the

SQUID loop. This technique allows vortices to be imaged with a spatial resolution of about 1 μm at variable temperature and magnetic field. The magnitude of the vortex signal is a direct measure of the amount of flux a vortex couples into the SQUID hole. In addition to the static local distribution of vortices, this technique can provide information on the dynamic behavior of vortices trapped in the SQUID loop if the beam is used as a local perturbation and the low-frequency noise induced by vortex motion is measured.

The sine-Gordon equation governing magnetic flux penetration into Josephson junctions with arbitrarily misaligned anisotropic superconducting banks has been derived by R. G. Mints (Tel Aviv) and V. G. Kogan (Ames Lab, Iowa State). The authors apply the theory to compute the mechanical torque on vortices in Josephson junctions at twin planes of *YBCO*-like material. This torque and its predicted angular dependence should be measurable in small fields, since flux penetration into twinned crystals evidently begins with the penetration of Josephson vortices along twin planes.

Flux Penetration

The magnetization of ideal type-II superconductors without bulk vortex pinning has been derived from first principles by E. H. Brandt (MPI-Stuttgart) for superconductors with constant thickness. The magnetization is irreversible because of a macroscopic geometric barrier for flux penetration at the edges, which yields a sharply defined entry field H_{en}. Above the irreversibility field $H_{rev} > H_{en}$, the magnetization becomes reversible and coincides with that of an ideal, appropriately defined ellipsoid. The author illustrates the results with numerical calculations of the field-increasing and field-decreasing magnetization of pin-free slabs, strips, disks, and cylinders with a variety of aspect ratios.

The dependence of the magnetic susceptibility components χ_1', χ_1'', χ_3', and χ_3'' upon the amplitude of the applied ac magnetic field have been calculated by G. M. Maksimova et al. (Nizhny Novgorod) for thin superconducting films ($d < \lambda$) in the form of narrow strips ($W << \lambda_\perp$, where d = film thickness, λ = London penetration depth, W = width, and $\lambda_\perp = 2\lambda^2/d$ = 2D screening length). The authors considered the behavior in two limits, one being when the edge barrier dominates the magnetization hysteresis and the other when bulk pinning dominates. The authors found that the signs of χ_3' and χ_3'' depend strongly upon which mechanism dominates the hysteresis.

The critical state in a thin superconducting circular disk ($d << R$) with an arbitrary magnetic-field dependence of the critical current density $J_c(B)$ has been analyzed by D. V. Shantsev (Oslo and St. Petersburg) et al. The authors assume either that $d \geq \lambda$ or, if $d < \lambda$, that $\lambda_\perp << R$, where d = film thickness, λ = London penetration depth, R = disk radius, and $\lambda_\perp = 2\lambda^2/d$ = 2D screening length. The authors derive and solve a set of coupled integral equations for the magnetic-flux and current-density distributions when a magnetic field B_a is applied perpendicular to the disk. The method accounts self-consistently for the suppression of J_c at places in the disk where, because of demagnetizing effects and self-fields, the local value of B is largest.

Theory

The thermodynamic properties of the SO(5) theory unifying antiferromagnetism (AF) and d-wave superconductivity (SC) have been explored extensively by X. Hu (NRIM) using Monte Carlo simulations with a classical model Hamiltonian. The author took into account thermal fluctuations both in the rotation of the SO(5) superspins between the AF and SC subspaces and in the phase variables of the SC order parameters. The author also investigated the consequences of an external magnetic field and found, for example, that short-range AF fluctuations are larger in the cores of vortex lines than elsewhere and that these fluctuations decrease continuously to zero with increasing symmetry-breaking (g) field. At intermediate g fields, the author finds a region of coexistence of the vortex-line lattice with long-range SC order and long-range AF order. Appearing in the corresponding simulated structure factor, surrounding the strong AF Bragg peaks at $\mathbf{Q} = (\pm\pi,\pm\pi)$, are superlattice spots identified with modulation by the triangular SC vortex lattice. The author suggests neutron-scattering measurements to search for these superlattice spots.

The fermionic states of the antiferromagnetically ordered vortex cores predicted to exist in the superconducting phase of the SO(5) model of strongly correlated electrons have been studied by B. M. Andersen et al. (Copenhagen). The authors stress that their model calculation gives a natural explanation of recent STM vortex-core studies by Ch. Renner et al. [Phys. Rev. Lett. **80**, 149 (1998); **80**, 3606 (1998)], which showed striking differences between *Bi-2212* and *YBCO.*

The interplay between lattice-symmetry breaking and superconducting order in a two-dimensional model of doped antiferromagnets with long-range Coulomb interactions and Sp(2N) spin symmetry has been investigated by M. Vojta and S. Sachdev (Yale) at zero temperature in the large-N limit. The authors propose a global phase diagram for the cuprate superconductors, and they also describe the quantum transitions between the phases, the evolution of their fermion excitation spectrum, and the experimental implications.

The development of a non-crossing approximation (NCA) for the effective cluster problem of the recently developed dynamical cluster approximation (DCA) is described in a

preprint by Th. Maier (Cincinnati and Regensburg) et al. The authors discuss the method in detail and present results for the one-particle properties of the Hubbard model. Near half filling, the spectra display pronounced features including a pseudogap and non-Fermi-liquid behavior due to short-ranged antiferromagnetic correlations.

Low-energy magnetic excitations of doped spin ladders have been studied by Y. Bai (POSTECH), using an effective Hamiltonian describing interactions of mobile spins and background spins. The author calculated the helicity modulus against fluctuations, both in the ladder plane and out of the plane, as functions of the doping concentration, leg number, and interaction strengths in the ladder. The system has the lowest energy in spiral phases with out-of-plane modes in addition to in-plane spirals. The author's results for the doping range for a gapped mode in odd-legged ladders are in agreement with existing numerical studies.

Two-leg spin-ladder systems have been studied analytically by Y. Bai and S.-I. Lee (POSTECH) using a t-J model including interchain spin exchange and interchain hopping terms. The authors map the spin part to a quantum sine-Gordon model via a bosonization method that accounts for phase fluctuations. The spin gap in the Luther-Emery phase evolves to gapless Luttinger-liquid phases in even ladders at certain doping levels. The authors estimate the transition temperature at which the conventional electron phase is deconfined to spinons and holons.

The low-energy charge excitations of a doped antiferromagnetic ladder have been modeled by J. P. Rodriguez (Madrid and California State, Los Angeles) using a system of interacting spinless fermions that live on the same ladder. A relatively large spin gap is assumed to freeze out all spin fluctuations. The author finds that the formation of rung hole pairs coincides with the opening of a single-particle gap for charge excitations along chains and with the absence of coherent tunneling between chains. The author also finds that such hole pairs condense into either a crystalline or superconducting state as a function of the binding energy.

The electronic structure of the high-T_c cuprates has been studied by J. Ashkenazi (Miami) on the basis of both large-U and small-U orbitals. The author finds a striped structure and three types of carriers: polaron-like stripons carrying charge, quasielectrons carrying charge and spin, and svivons carrying spin and lattice distortion. Anomalous properties of the cuprates and their transport properties are derived. The author finds that pairing results from transitions between pair states of quasielectrons and stripons through the exchange of svivons. The pairing results in superconductivity when the stripons conduction is coherent, and in a pseudogap phase when it is not.

As noted by B. K. Chakraverty (Grenoble), if phase coherence determines the superconducting transition temperature in the cuprates, it is of great interest to understand the role that phase-fluctuation dynamics plays in bringing about depletion of the superconducting condensate. The author presents a theory for how this occurs and shows that, in two dimensions, dynamic phase fluctuation or pair fluctuation gives rise to condensate depletion linear with temperature as $T \rightarrow 0$ in superconductors with nodes at the Fermi surface.

The effects of dilute *Zn* impurities on the uniform magnetic susceptibility have been calculated by N. Bulut (Koc) in the normal metallic state for a model of spin fluctuations in the layered cuprates. The author finds that scattering from extended impurity potentials can lead to a coupling of the $\mathbf{q} \sim (\pi,\pi)$ and $\mathbf{q} \sim 0$ components of the magnetic susceptibility $\chi(\mathbf{q})$. In the presence of antiferromagnetic correlations, this coupling can enhance the uniform susceptibility. The author discusses the implications of this result for experimental data on *Zn*-substituted $YBa_2Cu_3O_{7-\delta}$.

As reported by C. Grimaldi (EPFL), the effects of impurity and spin-orbit scattering potentials can strongly affect the Zeeman response of a d-wave superconductor. The author calculates both the phase diagram and the quasi-particle density of states within the Born approximation and finds that the spin-orbit interaction influences the Zeeman responses of d-wave and s-wave superconductors in a qualitatively different way.

The BCS-BEC (Bose-Einstein-condensation) crossover scenario within the superconducting state has been investigated by I. Kosztin (Chicago) et al., using a T-matrix approach that yields the ground state proposed by Leggett. Here the authors extend this ground-state analysis to finite temperatures and interpret the resulting physics. The authors find and examine the properties of two types of bosonic-like excitations of the system: long-lived, incoherent pair excitations and collective modes of the superconducting order parameter, which have different dynamics. The authors emphasize how, at finite T, BCS-BES approaches introduce an important parameter $\Delta_{pg}^2 = \Delta^2 - \Delta_{sc}^2$ into the description of superconductivity, where Δ is the excitation gap and Δ_{sc} is the superconducting order parameter.

Using a diagrammatic BCS-BEC crossover theory, J. Maly et al. (Chicago) have investigated the pseudogap onset temperature T*, the superconducting transition temperature T_c, and the general nature of the pseudogap phase. The theory is based on the pairing approximation of Kadanoff and Martin, which was further extended by Patton (KMP). This approach was driven by the objective to obtain BCS-like behavior in the weak-coupling limit. As the coupling constant g increases, the system crosses over to Bose-Einstein behavior. The authors' T_c equations, which

turn out to be rather simple as a result of the KMP scheme, reveal a rich structure as a function of g in which the pseudogap is found to compete with superconductivity.

The effects of critical superconducting fluctuations upon the scaling of the linear ac conductivity $\sigma(\omega)$ of a bulk superconductor slightly above T_c in zero applied magnetic field have been considered by R. A. Wickham and A. T. Dorsey (Florida). The authors derive a universal scaling function S(y) and find that it deviates only slightly from its Gaussian form, calculated earlier. The authors also compare their results with experimental measurements of the ac conductivity of $YBa_2Cu_3O_{7-\delta}$ near T_c, and they discuss the implications of their theory for such experiments.

A theory of mesoscopic fluctuations in disordered thin superconducting films in a parallel magnetic field has been developed by F. Zhou (Princeton). At zero temperature and in a sufficiently strong magnetic field, the superconducting state is predicted to undergo a phase transition into a state characterized by superfluid densities of random signs instead of a spin-polarized disordered Fermi-liquid phase.

A preprint by A. Kallio et al. (Oulu) shows that the upper critical field $H_{c2}(T)$ of an unconventional superconductor can be expressed in a simple way in terms of a single universal function f(t). Here $t = T/T^*$, where T^* is connected with the temperature-independent gap $2\Delta = 2k_BT^*$, and 2Δ is the binding energy of a pair in analogy with dissociation of molecules. The function f(t) determines the fraction of bosons (B^{++}) and fermions (h^+) at temperature T; it is obtained from a mathematical treatment of chemical equilibrium with respect to the reaction $B^{++} \Leftrightarrow 2h^+$. The authors show that this theory accounts for all the shapes of $H_{c2}(T)$ observed in several unconventional superconductors, including $Tl_2Ba_2CuO_{6+\delta}$ *(Tl-2201)* with $T_c = 15$ K.

The origin of superconductivity in electron-doped cuprates of composition $Ln_{2-x}Ce_xCuO_{4-z}$ *(Ln = Nd, Pr,* and *Sm)* is considered in a preprint by L. Jansen (ETH-Zürich) and R. Block (Amsterdam). The authors propose that the origin of superconductivity in these materials is due to indirect-exchange coupling between conduction electrons (quasiparticles) via diamagnetic oxygen anions, the mechanism the authors previously applied to the hole-doped cuprates. The authors argue that the electron-doped cuprates are, in fact, hole-doped because of overcompensation of doped excess positive charge by oxygen anions.

As noted in a preprint by D. F. Agterberg (Florida State), there now exists a wealth of experimental evidence that Sr_2RuO_4 is an odd-parity superconductor. Experiments further indicate that among the bands stemming from the *Ru* {xy,xz,yz} orbitals, the portion of the Fermi surface arising from the xy orbitals exhibits a much larger gap than the portions of the Fermi surface arising from the {xz,yz} orbitals. In this preprint, the author examines the role of impurities on such an orbital-dependent superconducting state within the Born approximation. In contrast to expected results for a nodeless p-wave superconductor, the unique nature of the superconducting state in Sr_2RuO_4 implies that a low concentration of impurities strongly influences the low-temperature behavior.

Andreev bound states in superconductor/ferromagnet (S/F) superlattices have been studied theoretically by V. Prokic and L. Dobrosavljevic-Grujic (Belgrade), assuming tunneling between S and F layers in the perpendicular direction. Andreev reflection at the S/F interfaces is found to be strongly affected by the exchange interaction h in F layers. In the ground state, zero-energy states (ZES) form on S and F layers when $h \neq 0$. For $h = 0$, corresponding to superconductor/normal (S/N) superlattices, ZES may appear in the nonequilibrium phase, $\phi = \pi$. This behavior is found for both s-wave and d-wave symmetry of the order parameter in S. The authors obtain the conditions for ZES as a function of h, the transfer integral t for movement of quasiparticles between S and F layers, and the ground-state phase difference ϕ_{eq} between two neighboring S layers.

Recent theoretical developments that relate to high-temperature superconducting Josephson junctions are discussed by G. Wendin (Chalmers): (a) isolated (S/I) and resonantly coupled (S/I/S) Andreev interface states, (b) d-wave models with resonantly coupled midgap states for ab-plane junctions, and (c) resonant-tunneling models for c-axis junctions.

Three preprints by M. W. Coffey (Colorado) provide underlying theory for the examination of spheres of superconducting or linear magnetic materials by magnetic force microscopy (MFM). One of these calculates the levitation force between a point magnetic dipole and a superconducting sphere (of uniform penetration depth λ) in the Meissner state. A second preprint shows how a penetration depth $\lambda(r)$ depending only upon the radial coordinate r could be determined from measurements of the levitation force at various distances from a superconducting sphere. The third shows how a permeability $\mu(r)$ depending only upon the radial coordinate r could be determined from measurements of the levitation force at various distances from a sphere made of a linear magnetic material.

Contributed by John R. Clem

Contents: Technology News is on page 8; Preprints begin on page 8; and Coming Events are on page 15.

High-T_c Update **is available without charge to interested persons. Recipients are expected to participate in this information exchange by sending us preprints, reprints, meeting news, research news, etc. Contributions to defray the cost of newsletter printing and mailing are welcome.**

TECHNOLOGY NEWS

(Also see Applications section of Nota Bene.)

This section describes progress in manufacturing, product development, and technology transfer in the high-T_c superconductivity field. Please send your contributions (product development information, news regarding technology transfer efforts, or any information you would like to share about your corporation or laboratory) to the editor.

Recently, American Superconductor Corporation (ASC) announced a contract with the Office of Naval Research (ONR) to design a 25,000-hp HTS ship propulsion motor for naval ship propulsion systems. The basic motor design is a variant on the one being employed for industrial HTS motors, which have been under development for the last decade. The company will also develop and demonstrate key motor components under the program. The application of HTS technology to ship propulsion is expected to yield inherently quieter motors that have much higher power density; that is, they are expected to be approximately one-fifth the size and weight of conventional motors of the same horsepower rating. (A conventional 25,000-hp ship propulsion motor is about the size of a city bus – the HTS model is expected to be about the size of a sport utility vehicle.) The company believes that the market for HTS ship propulsion motors for both commercial and defense applications will add significantly to the addressable market for HTS motors, which is already over $1 billion per year based on industrial motor applications. This first contract for HTS ship propulsion motors has a value of $2 million, of which the company expects to recognize approximately $1.5 million over the next 12 months. The remainder will be directed to parallel development efforts at the ONR, the Naval Research Laboratory, and the National High Magnetic Field Laboratory. For further information, contact American Superconductor Corporation, Two Technology Drive, Westborough, MA 01581; telephone (508) 836-4200; telefax (508) 836-4248. Media contact is Kevin Coates, telephone (202) 434-8308, e-mail kcoates@washington.com.

The two corporations, OMICRON Vakuumphysik GmbH and Oxford Instruments Research Instruments, have recently announced their cooperation in the development of low-temperature scanning-probe microscopy systems. OMICRON has, over the past years, invested heavily in the development of low temperature microscopes, and has rapidly extended its range of products for low-temperature SPM applications. Oxford Instruments has, for many years, been involved in the field of cryogenic applications. The cooperation will combine the core skills and expertise of both partners in the creation of a new class of research instruments and intends to open up new development perspectives to cater better to the increasing demand from the research community and to meet the stringent requirements of complex applications. For further information, contact Michael Sander, Marketing Manager, OMICRON Vakuumphysik GmbH, Idsteiner Str. 78, D-65232 Taunusstein, Germany; telephone +49 61 28 9870; telefax +49 61 28 987185; Web site http://www.omicron-instruments.com/ or http://www.omicron.de/. Or contact Steve Vale, Director of Marketing and Systems, Oxford Instruments Research Instruments, Tubney Woods, Abingdon, Oxfordshire, United Kingdom OX13 5QX; telephone +44 1865 393200; telefax +44 1865 393333; Web site http://www.oxford-instruments.com/.

Contributed by Sreeparna Mitra

PREPRINTS

To obtain a particular preprint, contact the first author at the address given at the end of the citation. Help us expand this list by sending us your complete preprint. **Please specify where and when your paper was submitted.** An * next to an entry indicates it is a correction or revision of a previous entry. PACS codes and/or key words are given at the end of the citation. For help on using or submitting your preprint to the cond-mat e-print archive at Los Alamos (Subject class: Superconductivity), go to http://xxx.lanl.gov/help/.

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COMING EVENTS

*(An * indicates a previously listed event. Also see complete listing of upcoming conferences and workshops at our Web site http://www.iitap.iastate.edu/htcu/comevents.html.)*

Oct. 11 - 22, 1999: Fourth Training Course in the Physics of Correlated Electron Systems and High-T_c Superconductors, Vietri sul Mare, Salerno, Italy. Aimed at postdoc-level researchers, the school will offer the opportunity to meet various experts from different physics contexts, all relevant to the investigation of strongly correlated electron systems. The proposed project of practical training courses intends to promote theoretical research in the field by putting together senior researchers with outstanding experience and skill and young researchers. Courses will be offered to 25 young (under 35) European researchers. The registration fee is $250. A limited number of grants for European researchers, covering part of the costs, will be available. Topics are theory of the spin-polaron for 2D antiferro-magnets, magnetic and orbital ordering in cuprates and manganites, and Bose-Einstein condensation in traps. Application forms and grant request forms are available from Prof. F. Mancini, Dipartimento di Scienze Fisiche "E. R. Caianiello," Università di Salerno, Via S. Allende, I-84081 Baronissi (SA), Italy; telephone +39 089 965 322; telefax +39 089 965 275; e-mail mancini@physics.unisa.it.

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