Condensed Matter Physics Research (CMP) by NSLS Staff

<u>NSLS Scientific Staff conducting CMP Research</u>:

Lonny Berman	X-ray Standing Wave Studies (X25 Program Responsible)
Wolfgang Caliebe	Soft condensed matter, Inelastic x-ray scattering (X18B, X19A Program Responsible)
Larry Carr	Superconductivity, Bad Metals (U12 Far IR Program Responsible)
Steve Dierker	Soft Condensed Matter, Magnetism, Electronic structure of materials (U10A, X13A, Chair NSLS)
Steven Ehrlich	Low temperature scattering (Experimental Operations Coordinator)
Jerry Hastings	High Energy X-ray scattering, Spallation Neutron Target Development (X13, X17 and Long Range R&D Program Responsible, On leave at SSRL in FY 2002)
Steven Hulbert	Auger-Photo Electron Coincidence Spectroscopy (APECS), VUV and soft x-ray optics development for high resolution spectroscopy (U13UB and Low Energy Science Program Responsible)
Erik Johnson	Photo-Fabrication R&D, DUV-FEL Development (X14B, X27B, DUV-FEL and ESG Program Responsible)
Chi-Chang Kao	Magnetism, Magnetic materials, Electronic structure of materials under high Pressure, Micro-beam applications, High energy resolution x-ray fluorescence (X13,X21 and High Energy Science Program Responsible)
Cecilia Sanchez-Hanke	Magnetism, Magnetic materials (X13A Program Responsible)
Brian Sheehy	Optical Physics, DUV-FEL (DUV-FEL Program Responsible)
D. Peter Siddons	High Energy Scattering, Perfect crystal optics (X6B, X12A, X27A Program Responsible, Detector and Control Development)
Elio Vescovo	Electronic structure and magnetism in thin films and multilayers, Spin polarized angle resolved photoemission (U5U Program Responsible)
Zhong Zhong	High Energy Scattering, Perfect crystal optics (X17 Program Responsible)

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Introduction:

Following the commissioning phase of a scientific facility, it is essential to invent, adapt and improve new technologies so that the specification and performance of the facility is upgraded over its lifetime. It is equally important that staff keep their expertise and research interests at the cutting edge. In this way, they can contribute, based on their unique experience, to the present and next generation of experiments at existing facilities and to the specification and R & D on which the next generation of facilities will be based.

A synchrotron radiation facility such as the National Synchrotron Light Source (NSLS) supports a very wide range of science which is dependent on the breadth of the electromagnetic spectrum which is generated. Scientists from many disciplines use radiation from the far infra-red (wavelength = 1.2 mm, Energy = 1 meV) through to extreme gamma rays (wavelength = 4 fm, Energy = 300 MeV). All aspects of the facility need continual improvement, development and research including the source itself, the optics of beamlines, experimental concepts and the performance of detectors.

Individual staff members work, in collaboration with in-house scientific, professional and technical staff and with user groups from other BNL departments, PRTs and general users to create and operate state-of-the-art stations relevant to the scientific needs and ambitions of the community. A listing of NSLS scientific staff most closely aligned with the Condensed Matter Physics research programs is provided along with a representative selection of publication references from fiscal years 1999 through 2001.

Highlights: The main focus of the activities summarized here is on the development of new experimental techniques in the application of synchrotron radiation to materials and condensed matter physics research. Close interactions with the user community and other related core research programs at BNL are essential to this effort.

Magnetism and magnetic materials:

X-ray magnetic circular dichroism (MCD) is becoming a routine spectroscopic tool in magnetism research and magnetic materials development. With the funding from the facility initiative, a new soft-x-ray grating monochromator beamline, X13A, has been constructed and commissioned recently. The energy range of the new monochromator extends from 250 eV to 1.6 keV. This photon energy range is particularly important because it includes both the $L_{2,3}$ absorption edges of the 3d transition elements and the $M_{4,5}$ absorption edges of the rare earth elements. We have also completed the hard-x-ray beamline, X13B, for hard-x-ray MCD and magnetic x-ray scattering use. The monochromator will cover the K edges of 3d transition elements and the $L_{2,3}$ edges of the rare earth elements. The radiation source of both beamlines is the time-varying Elliptically Polarized Wiggler (EPW). The switching capability of EPW allows the use of phase sensitive detection for the study of extremely small induced-moments and interfacial spins. To complete these two beamlines, focusing mirrors for both beamlines are funded by NSLS in fiscal 2001.

In addition, NSF has funded two new high-field superconducting magnets for magnetism research at NSLS recently; a 16T magnet to be used in far IR spectroscopy and a 10T magnet to be used in X-ray spectroscopy. And, a new magnetic imaging technique based on the use of coherent soft-x-ray is being developed with a three year LDRD program.

X-ray Spectroscopic Study of materials under high pressure:

The study of electronic structure of materials under high pressure at NSLS has evolved over the last few years. The successful demonstration experiments at NSLS, carried out over the last few years through a collaboration between NSLS staff and David Mao's group at Geophysical Laboratory, has made inelastic x-ray scattering the principal scientific program of the HP-CAT. It is anticipated that after HP-CAT is constructed, inelastic x-ray scattering study of mega-bar samples will mostly be carried out there. The effort at NSLS is now focused on x-ray absorption spectroscopy. A new micro-focusing system and backscattering detection scheme have been developed for this purpose recently. The changes in Pr 5d band associated with the large volume collapse transition in Pr were measured for the first time. We expect that these developments will clearly be useful in the understanding of lattice effects in both CMR and High Tc materials.

Sagittal Focusing of High-Energy Synchrotron X-rays with Asymmetric Laue Crystals:

A double focusing Laue configuration for focusing high energy x-rays was developed, tested, and recently installed on the hard x-ray wiggler beamline X-17B. By taking advantage of the materials properties and the high energy of the x-rays, this unique instrument realizes a net gain in flux density on sample of 600 to 800 for energies above 25 keV as compared to conventional double crystal bragg reflection monochromators.

Micro-beam applications:

The in-vacuum undulator (IVUN) provides a great opportunity for micro-beam applications. Based on the IVUN task force recommendation, we have started a new program at X13. Recently, a Kirkpatrick-Baez pair of elliptically figured mirrors, fabricated using a novel differential-deposition technique, was designed and implemented. A focused spot size of 3 microns (vertical) by 9 microns (horizontal) was achieved. The system has been used in characterization of multiple quantum well structure, high-pressure x-ray spectroscopy, and biomedical imaging.

Auger Photo-electron Coincidence Spectroscopy:

The novel technique of Auger-photoelectron coincidence spectroscopy performed using synchrotron radiation was developed by a collaboration between Eric Jensen (Brandeis U.), Robert Bartynski (Rutgers U.), and S. L. Hulbert (NSLS) in the mid-1980's. This technique, which measures only photoelectrons which have arrived at the detectors of two electron energy analyzers in time coincidence, enables one to acquire photoemission spectra from solid surfaces with unprecedented discrimination. During the past three fiscal years ('99, '00, and '01), this group has investigated the soft x-ray coincidence core photoelectron and Auger spectra (taken in time coincidence with Auger and core photoelectrons, respectively) of clean transition metal surfaces and thin metal surface alloys on these surfaces. The combination of both types of coincidence spectra (photoelectron and core) for two spin-orbit-split soft x-ray core levels (e.g. Ag 3d3/2 and 3d5/2) provides a measurement of the intrinsic Auger lineshape in these systems. These kinds of spectra have been acquired and compared to theoretical lineshapes in order to provide insight into the role of hole-hole correlations in various clean 3d and 4d metal and thin metal surface alloy systems, including: Ag, Cu, Ru, Ag/Cu, Pd/Cu, and Pd/Ag.

Electronic Structure and Magnetism In Thin Films and Multilayers:

Ultra-thin films and multilayers have distinct magnetic properties that have no analogues in bulk systems. Striking examples include the indirect exchange-coupling between non-adjacent magnetic layers, spin-dependent transport phenomena, and interface and surface magnetic anisotropies. These unique properties have both fundamental and technological relevance so it is not surprising that the study of thin films and multilayers has recently become one of the principal fields of research in magnetism.

The investigation of the electronic structure of these 2-dimensional systems provides a basis for understanding their magnetic behavior. In recent years, the increasing availability of synchrotron radiation has contributed greatly to the development of spectroscopic methods for the study of magnetism in thin films. The high intensity available, especially on insertion-device beamlines, has made it practical to investigate these systems with complex techniques such as spin-resolved photoemission. Moreover the photon polarization control possible at a synchrotron (both circular and linear polarized beams are available) has enormously enhanced the range of possible magnetic measurements.

In fact, by introducing polarization control in traditional techniques such as absorption, reflection and photoemission, magnetic dichroism effects can be readily observed. Synchrotron radiation spectroscopy can provide a detailed description of magnetic and electronic properties of thin films a few atomic layers thick. For example, the band dispersion, the magnetic moments, the magnetic anisotropy and susceptibility, the Curie temperature and the critical behavior at the magnetic phase transitions can be determined.

The U5UA beamline at NSLS is a premiere facility to perform spin-polarized angular-resolved photoemission experiments on ultra-thin films and multilayers. This technique, which would be nearly impossible without the high intensity of synchrotron radiation sources, provides a unique tool to experimentally map the dispersion of the spin-polarized bands of ferromagnetic solids. Furthermore its pronounced surface-sensitivity makes it highly suitable to extract information about the electronic structure of surfaces. At the U5UA beamline are routinely prepared *in-situ* a variety of epitaxial magnetic thin films, ranging from "simple" 3*d* and 4*f* ferromagnetic materials to more complex systems like alloys of two or more elements or even stoichiometric compounds.

Infrared Studies of Electronic Properties of Materials:

The NSLS research at infrared beamlines U12IR and U10 focuses on the electronic properties of materials. Systems being explored include systems near a metal-insulator transition (in collaboration with BNL-Physics), superconductivity and semiconductors (collaboration with U. Florida).

The Physics Department initiative to study complex metals is investigating layered metal-oxide systems that often lie near a metal-insulator (M-I) transition. The charge transport in these materials is not understood, but shows similarities to other disordered 2D systems such as ultra-thin, amorphous metal films and discontinuous (granular) metal films. The infrared properties of various discontinuous metal films have been studied across much of the infrared, but the low frequency dynamics have not been fully explored. The NSLS infrared research program at beamline U12IR is actively studying discontinuous metal films to 3 mm wavelengths, and quantitatively comparing with effective medium theories.

The NSLS time-resolved IR spectroscopy program (collaboration with U. Florida) exploits the short duration pulses of light, produced by the VUV ring, to study electron dynamics on a sub-nanosecond time scale. Material systems to be explored include semiconductor materials and device structures, synthetic metals ("photo-doping"), and superconductors. We are presently concentrating on the dynamics of Cooper pair breaking and recombination in superconducting lead films. The recombination process has been probed by time-resolved techniques on only a few occasions, and unexpected behaviors were observed, e.g., a bi-exponential decay. The NSLS program uses far infrared spectroscopy to directly probe the electronic states near the superconducting gap energy along with the strength of the pair condensate. We have also observed a bi-exponential decay with a fast decay component of ~100ps.

Spectroscopic studies of electronic and magnetic structure

The research program includes studies of electronic structure and magnetic structure of highly correlated systems of transition metals and rare-earths, semiconducting systems, magnetic thin film and multilayer systems, emphasizing the use of synchrotron radiation facilities. Data are analyzed using theoretical results both from density-functional calculations and from solutions of model many-body Hamiltonians. The spectroscopy is directed at aspects of the electronic structure which either underlies or directly responsible for novel ground state phenomena, such as metal-insulator transitions, mixed valence, Kondo resonance, heavy-fermion, and high temperature superconductivity. Furthermore, the spectroscopy by means of magnetic circular/linear dichroism, provides rich information on the magnetic structure such as element specific spin and angular moments and magnetic hysteresis. The program involves collaborations with members of material, theory, and spectroscopy communities at universities, at industrial laboratories, and at other national laboratories both in the USA and abroad.

The specific research subjects are selected for a variety of reasons. They may possess interesting physical phenomena or physical systematics that are deeply related to high-technology applications, or they may be newly discovered materials displaying novel physical behaviors. The following examples are representative of the research currently in progress.

Electron/hole doped mixed valent materials

These systems show interesting physical phenomena such as high temperature superconductivity, real-space charge ordering, metal-insulator transitions, colossal magnetoresistance, etc. Recently, we have performed electron spectroscopy studies on a colossal magnetoresistant system, doped manganites. Our study provides direct information on the electronic structure and the magnetic properties. A few representative results include; a spin-resolved photoemission study that provides the first observation of the half-metallic ferromagnet; the combined study of the spin-resolved photoemission and the magnetic circular dichroism. This latter study provides complete information on the depth profile of the magentization behavior, which has important implications for ferromagnetic oxide thin film and multilayer research.

Magnetic thin films and multilayers

Recently, these systems have attracted so much attention due to their potential technological applications in a variety of magnetic devices. The systems generally consist of 3*d* transition metals, and soft x-ray magnetic circular dichroism has been well known as an one of the most powerful tools for probing the magnetic structure of the 3*d* transition metal thin film and multilayers. Our research can probe the details of magnetic properties of the systems such as the enhancement or reduction of the magnetic moment on a certain thin film, layer-layer magnetic interaction on the multilayer, chemical and magnetic information on the interface, etc.

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