UVSOR Facility

IX-P Development of the UVSOR Light Source

IX-P-1 Design and Construction of Variably Polarized Undulator

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A new undulator was designed and constructed, which will provide bright VUV radiation to a beam-line BL7U at UVSOR-II. The period length and number of periods are 76 mm and 40, respectively. Permanent magnet blocks made of Nd-Fe-B are arranged in Apple-II configuration. The undulator has capability of producing linear polarized light in both planes (horizontal and vertical) and circular polarized light in both directions (right handed and left handed).

A new beam duct for this undulator was also designed and constructed. The vertical aperture is 18 mm, which is narrowest in the UVSOR-II storage ring. The inner wall was covered by a Cu layer of 100 micron thick to reduce resistive wall impedance. The duct is pumped by two sputtering ion pumps and three NEG pumps.

The duct was successfully installed in the ring. Soon after finishing the field measurement, the undulator will be installed in the ring.

IX-P-2 Upgrade of Booster Synchrotron Magnet Power Supplies

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Top-up operation is a new technology to keep the intensity of electron beam circulating in a storage ring approximately constant by replenishing electrons frequently, typically with an interval of several minutes. The constant intensity of synchrotron radiation (SR) realized by this scheme will enable more accurate experiments.

Preparing for the top up injection, energy upgrade of the booster synchrotron is in progress at UVSOR-II. The maximum energy of the booster synchrotron had been limited at 600 MeV by the capacity of the magnet power supply, which is lower than the operation energy of the storage ring, 750 MeV. New power supplies compatible with the full energy injection were designed and constructed. In July, 2006, the power supplies were replaced. The acceleration to 600 MeV was successfully tested. Soon, full energy acceleration will be tested.

IX-P-3 One Watt Lazing in Deep UV Region of UVSOR-II Free Electron Laser

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The shortest wavelength of the UVSOR free electron laser (FEL) had been at 239 nm for many years. However, the low emittance owing to the new magnetic lattice introduced in 2003 and the higher peak current owing to the new RF cavity installed in 2005 have drastically increased the gain of FEL. The higher gain have made the FEL oscillate in deep UV region with high output power. The shortest wavelength is now 215 nm with output power of several milli-watt level. Lasing at shorter wavelength around 200 nm will be tried in near future. Average output power exceeding one watt was recorded at the wavelength of 230 nm. Some users experiments using this high power deep UV laser have started and a few others are under planning.

IX-P-4 Production of Coherent Terahertz Radiation by Laser Bunch Slicing Method

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Laser bunch slicing is a technology to slice out a part of an electron bunch moving with relativistic velocity in particle accelerators. At UVSOR-II, an Ti:Sa laser which can be synchronized with the RF acceleration of the electron storage ring was installed in 2005. By using the existing optical system and the optical klystron for the free electron laser experiment, we have started a laser bunch slicing experiment, aiming to produce intense terahertz radiation. As a result of the interaction between the laser pulse and the electron bunch, a dip is created on the longitudinal density structure of the electron bunch. The width of the dip is basically same as the laser pulse width; sub-pico-second in our case. An electron bunch which has such structure emits intense coherent terahertz radiation. The terahertz radiation synchronized with the laser injection was successfully observed at an existing beam-line BL6B, which is one of the most powerful infrared beam-line in the world. The observed intensity of the terahertz pulses is $10^{4–5}$ times higher than that of normal synchrotron radiation. The intensity was observed to be proportional to the square of the electron intensity. This clearly indicates that the observed terahertz pulses are produced by coherent radiation.

IX-P-5 Coherent Harmonic Generation by Using Ultra-Short Pulse Laser

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Coherent harmonic generation was successfully demonstrated at UVSOR-II. In the experiment, ultra-short laser pulses are injected to the storage ring. The laser pulses and the electron pulses interact in an optical klystron type undulator. The electrons are either accelerated or decelerated depending on the phase of the laser field. As the result, a periodic energy modulation is created on the electron pulse, whose period is exactly same as the laser wavelength. This energy modulation is converted to a density modulation, which has a periodicity of laser wavelength and its higher harmonics. Electron bunches which have such a longitudinal density structure emit coherent radiation at the laser wavelength and also at its higher harmonics. Intense radiation at the third harmonic (267 nm) synchronized with the laser injection was successfully observed. The intensity of the coherent harmonics was proportional to the square of the intensity of the electron pulses. This clearly indicates that the observed radiation is a coherent harmonic radiation.

IX-Q Researches by the Use of UVSOR

IX-Q-1 Experimental Investigation of Core-Valence Double Photoionization

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[*Phys. Rev. Lett*. **97**, 053003 (2006)]

Core-valence double photoionization has been observed in Ne atoms and N_2 molecules using a magnetic bottle time of flight spectrometer. The multi-electron coincidence datasets give complete information on the energy correlations between all emitted electrons, which supports a detailed description of the core-valence double photoionization process including direct spectroscopy of the core-valence doubly ionized states, the final states populated by their Auger decay and details of the dynamics of core-valence double photoionization for selected states.

IX-Q-2 Efficient Production of Metastable Fragments around the 1s Ionization Threshold in N_2

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([1]LCP-MR)

[*J. Phys. B: At., Mol. Opt. Phys*. **38**, 3597 (2005)]

Metastable formation has been investigated in the inner-shell region of N_2. Enhanced N* formation has been observed around the 1s threshold, and is shown to result from dissociation of high N_2^{+*} Rydberg states. These N_2^{+*} states are populated by spectator Auger decay from the core-excited states, as well as by the recapture of slow photoelectrons into the Rydberg orbitals. The present measurement demonstrates that the metastable observation is a new and sensitive tool to study the decay dynamics of core-excited states and the photoelectron recapture due to post-collision interaction.

IX-Q-3 Anisotropic Fragment Emission on Valence Photoionization of CF_4

HIKOSAKA, Yasumasa; SHIGEMASA, Eiji

[*J. Electron Spectrosc. Relat. Phenom*. **152**, 29 (2006)]

Photoion images from photoionization of CF_4 with an isotropic geometry have been measured in the photon energy range of 17–60 eV. Fragment ion emissions below 40 eV are found to be anisotropic with respect to the electric vector of the linearly polarized light. This observation directly implies that the T_d symmetry is broken on the dissociative photoionization process. The excited states associated with the transitions to the unoccupied orbitals are subject to symmetry lowering, which promotes the anisotropic fragment emissions from the highly-symmetrical molecule.

IX-Q-4 Auger Decay of Ne 1s Photoionization Satellites Studied by a Multi-Electron Coincidence Method

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[*J. Phys. B: At., Mol. Opt. Phys.* **39**, 3457 (2006)]

The Auger decay of Ne 1s photoionization satellite states is studied with a magnetic-bottle multi-electron coincidence method. The energy correlations among the multi-electrons associated with the double Auger decay from the Ne^+ satellite states are extracted from the accumulated coincidence dataset. It is concluded that the Ne^{2+} states populated through the initial Auger decays from the Ne^+ satellite states can be excited states that lie

above the Ne^{3+} threshold. Their subsequent decay produces slow electrons in the 0–25 eV kinetic energy range. Possible assignments of the intermediate Ne^{2+} and the final Ne^{3+} states are given.

IX-Q-5 Inner-Valence States of N^{2+} and the Dissociation Dynamics Studied by Threshold Photoelectron Spectroscopy and Configuration Interaction Calculation

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[*J. Chem. Phys.* **124**, 234306 (2006)]

The N_2^+ states lying in the ionization region of 26–45 eV and the dissociation dynamics are investigated by high-resolution threshold photoelectron spectroscopy and threshold photoelectron-photoion coincidence spectroscopy. The threshold photoelectron spectrum exhibits several broad bands as well as sharp peaks. The band features are assigned to the N_2^+ states associated with the removal of an inner-valence electron, by a comparison with a configuration interaction calculation. In contrast, most of the sharp peaks on the threshold photoelectron spectrum are allocated to ionic Rydberg states converging to N_2^{2+}. Dissociation products formed from the inner-valence N_2^+ states are determined by threshold photoelectron-photoion coincidence spectroscopy. The dissociation dynamics of the inner-valence ionic states is discussed with reference to the potential energy curves calculated.

IX-Q-6 Electron Correlation in Xe 4d Auger Decay Studied by Slow Photoelectron–Auger Electron Coincidence Spectroscopy

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[*J. Phys. B: At., Mol. Opt. Phys.* **39**, 1017 (2006)]

Two different experimental methods, namely threshold electron–Auger electron coincidences and slow photoelectron–Auger electron coincidences are applied to investigate the Xe 4d Auger decay in the near-threshold region and reveal the essential role of electron correlation. The coincidences allow us to select the different channels for the 4d hole Auger decay which lead to different final states of the Xe^{2+} ion: $5s^{-2}(^1S_0)$, $5s^{-1}5p^{-1}(^1P_1)$, $5p^{-2}(^1S_0)$, $5p^{-2}(^1D_2)$, $5p^{-2}(^3P_{0,1})$ and $5p^{-2}(^3P_2)$. Measurements of the threshold electrons with the first method reveal strong PCI distortion of electron spectra in all channels. Comparison with calculations carried out in the framework of the quantum-mechanical PCI model allows us to clarify the dynamics of threshold electron production. In the $5p^{-2}(^1S_0)$ channel, the main contribution comes from the PCI retardation of slow photoelectrons. In the $5p^{-2}(^1D_2)$ and $5p^{-2}(^3P)$ final state channels, additional processes of PCI recapture followed by valence multiplet decays play a role at and below the N_4 and N_5 thresholds. The slow photoelectron spectra measured by the second method reveal also a strong PCI distortion. Analysis within the framework of the eikonal model shows the influence of the Auger electron on the PCI distorted line shapes.

IX-Q-7 Development of Symmetry-Resolved Zero-Kinetic-Energy Photoelectron Spectroscopy for Probing Multielectron Processes

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[*Rev. Sci. Instrum.* **77**, 036112 (2006)]

A new experimental setup for probing multielectron processes in molecular inner-shell ionization regions has been developed. Symmetry-resolved zero-kinetic-energy (ZEKE) spectra have been measured by scanning the photon energy along with monitoring the intensity of the coincidence signals between ZEKE electrons and fragment ions detected at 0° and 90° relative to the electric vector of the light. The actual performance of the method is illustrated by using it to reveal the symmetry decomposition of the multielectron processes, such as double excitations and shake-up satellites, in the *K*-shell ionization region of nitrogen.

IX-Q-8 Iron-Based Heavy Quasiparticles in $SrFe_4Sb_{12}$: An Infrared Spectroscopic Study

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[*Phys. Rev. B* **73**, 214416 (5 pages) (2006)]

Temperature-dependent infrared reflectivity spectra of $SrFe_4Sb_{12}$ has been measured. A renormalized Drude peak with a heavy effective mass and a pronounced pseudogap of 10 meV develops in the optical conductivity spectra at low temperatures. As the temperature decreases below 100 K, the effective mass (m^*) rapidly increases, and the scattering rate ($1/\tau$) is quenched. The temperature dependence of m^* and $1/\tau$ indicates that the hybridization between the Fe 3d spins and the charge carriers plays an important role in determining the physical properties of $SrFe_4Sb_{12}$ at low temperatures. This result is the clear evidence of the iron-based heavy quasiparticles.

IX-Q-9 Optical Pseudogap from Iron States in Filled Skutterudites AFe_4Sb_{12} (*A* = Yb and Ca, Ba)

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[*Phys. Rev. Lett.* **96**, 037406 (2006)]

Optical investigations are presented of the filled skutterudites AFe$_4$Sb$_{12}$ with divalent cations A = Yb, Ca, Ba. For each of these compounds a very similar pseudogap structure in the optical conductivity develops in the far-infrared spectral region at temperatures below 90 K. Highly accurate local-density approximation electronic band structure calculations can consistently explain the origin of the pseudogap structure generated largely by transition metal 3d states. In particular, a 4f-conduction electron hybridization or strong correlations can be ruled out as origin for the pseudogap.

IX-Q-10 Continuity of Ce 4f Electronic Structure across the Quantum Critical Point: A Resonant Photoemission Study on $CeNi_{1-x}Co_xGe_2$

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[*Phys. Rev. B* **72**, 220405(R) (4 pages) (2005)]

Ce 3d–4f and 4d–4f resonant photoemission spectroscopies have been performed on the heavy-fermion compound $CeNi_{1-x}Co_xGe_2$, where the ground-state properties systematically change from the magnetic ($0 < x < 0.3$) to nonmagnetic ($0.3 < x < 1.0$) regime *via* the quantum critical point (QCP, $x = 0.3$). Co-substitution dependence of the bulk Ce 4f electronic structure shows gradual evolution of Kondo resonance at the Fermi level together with the reduction of the Ce 4f^0 final state in agreement with the single impurity Anderson model (SIAM). The SIAM analysis shows that the Kondo temperature and specific-heat coefficient change continuously from the weakly hybridized $CeNiGe_2$ to strongly hybridized $CeCoGe_2$. These indicate that the Ce 4f electronic structure of $CeNi_{1-x}Co_xGe_2$ changes continuously through the QCP.

IX-Q-11 Optical Study on Clathrates $Sr_8Ga_{16}Ge_{30}$ and β-$Eu_8Ga_{16}Ge_{30}$

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[*Physica B* **383**, 122–123 (2006)]

The optical reflectivity spectra of clathrates $Sr_8Ga_{16}Ge_{30}$ and β-$Eu_8Ga_{16}Ge_{30}$ have been measured to investigate their electronic structure. A clear Drude shape was observed in the spectrum of $Sr_8Ga_{16}Ge_{30}$. On the other hand, a broad Drude shape due to magnetic scattering by Eu 4f electrons and a peak originated from Eu 4f states were observed in the spectrum of β-$Eu_8Ga_{16}Ge_{30}$. No clear change of optical conductivity due to the magnetic order was observed in β-$Eu_8Ga_{16}Ge_{30}$ and no evidence of the rattling in $Sr_8Ga_{16}Ge_{30}$ observed in contrast to α-$Eu_8Ga_{16}Ge_{30}$. These results essentially originated from the large carrier density of these materials.

IX-Q-12 Infrared Study on Electronic Structure of SrT_4Sb_{12} (T = Fe, Ru)

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[*Physica B* **383**, 137–139 (2006)]

The temperature dependent optical conductivity spectrum of strontium filled skutterudites SrT_4Sb_{12} (T = Fe, Ru) has been measured to investigate the origin of the heavy-fermion-like physical properties and the enhancement of the thermopower at around 50 K. The optical conductivity spectra of T = Fe and Ru at the temperature of 7 K have peak structures at the photon energies of 24 and 190 meV, respectively. From the band structure calculation, the peaks correspond to the density of states (DOS) mainly originating from the Fe 3d and Ru 4d characters locating in the unoccupied states, *i.e.*, $SrFe_4Sb_{12}$ has a very narrower band near the Fermi level (E_F) than $SrRu_4Sb_{12}$. The shape of DOS near E_F is concluded to be the origin of the unconventional physical properties.

IX-Q-13 Angle-Resolved Photoemission Study on $CeTe_2$

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[*Physica B* **378-380**, 767–768 (2006)]

We have used angle-resolved photoemission spectroscopy as a function of excitation energy to elucidate the three dimensionality at the electronic structure of quasi-two-dimensional strongly correlated Ce 4f electron compound $CeTe_2$. We observed that there are two types of Te 5p bands along ΓZ symmetry line at the valence band, one is non-dispersive bands and the other is dispersive one. While the former is ascribed to the Te 5p bands at two-dimensional Te layer relating to the CDW formation, the latter to one at CeTe double layers.

IX-Q-14 High-Resolution Photoemission Spectroscopy of $CeNiGe_2$ and $CeCoGe_2$

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[*Physica B* **378-380**, 825–826 (2006)]

We have performed the high-resolution photoemis-

sion spectroscopy on the isostructural heavy fermion compounds, $CeCoGe_2$ and $CeNiGe_2$, as the representative samples of $CeNi_{1-x}Co_xGe_2$ to investigate the origin of the wide Ce 4f characters from the magnetic (x = 0) to non-magnetic regime (x = 1) *via* the quantum critical point (x = 0.3). We directly observed a Kondo peak, whose width corresponds to the Kondo temperature, in both materials but the crystal field splitting only in $CeNiGe_2$. Both the Kondo temperature and the crystal field splitting are concluded to be affected by the hybridization between Ce 4f and Ni/Co 3d states.

IX-Q-15 Infrared Absorption in Heavy Fermion System $CeNi_{1-x}Co_xGe_2$

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[*Physica B* **378-380**, 823–824 (2006)]

We have measured optical conductivity spectra $\sigma(\omega)$ of $CeNi_{1-x}Co_xGe_2$ at several temperatures. The $\sigma(\omega)$ spectra exhibit two peaks in middle infrared regions at low temperatures. The peaks show a strong temperature dependence and disappear above a characteristic temperature (T^*) at last. We suggest that the middle infrared peaks arise from transitions between d-states below E_F and c–f hybridization states just above E_F.