# DATA ACQUISITION SYSTEM FOR THE ANGLE INTREGRAL PHOTOEMISSION SYSTEM AT THE SIAM PHPTON LABORATORY

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*Received: Feb 14, 2005; Revised: Aug 3, 2005; Accepted: Aug 4, 2005*

## Abstract

**The new data acquisition system for an angle-integral photoemission system has been developed to be used at the experimental station of the BL4 beamline of the Siam Photon Laboratory. The system has been designed to take advantage of the salient properties of synchrotron light. The system provides different modes of measurements such as the energy distribution curve, constant initial state and constant final state modes of measurement. This report describes the design of the acquisition system. The commissioning results are also reported.**

**Keywords: Photoemission, data acquisition, energy analyzer, synchrotron light**

## Introduction

The physical and chemical properties of surfaces of solid materials are dependent on the arrangement of atoms, the distribution of electrons, and their response to external changes. Knowing the electronic structure of surfaces can lead to more accurate predictions of the properties of the surfaces. Many works have been concentrated on theoretical predictions of the electronics structure on different kinds of materials (Hüfner, 1996). The electronics structure can also be measured directly by using the angle-resolved photoemission (ARPES) technique (Kevan, 1992). At the Siam Photon Laboratory, the ARPES system has been designed and constructed to be used for the investigations of the electronics structure of solids and surfaces of solids. The details of the system have been reported elsewhere (Songsiriritthigul *et al.,* 2001). The Thermo VG Scientific ARUPS10 energy analyzer is used for ARPES measurements. In addition, the system is equipped with a Thermo VG Scientific CLAM2 energy analyzer, which has been designed for Auger electron spectroscopy (AES) and X-ray photoelectron spectroscopy (XPS) in the analysis of impurities on the surface of samples. The CLAM2 analyzer can also be used for ultraviolet photoelectron spectroscopy (UPS). The experimental station is connected to the BL4 beamline at the Siam Photon Laboratory providing photons with tunable energy between 20 eV and 240 eV for photoemission experiments.

To take advantage of the salient properties of synchrotron light, a new data acquisition system for Angle-integral Photoemission (AIPES) experiments has been developed. Thanks to a tunable light source, different types of

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experiments can be performed with the integrated photoemission spectrometer, e.g. resonant photoemission experiments. Thus the availability of the AIPES technique will greatly enhance the capability of the experimental station of the BL4 beamline. Hence, it opens opportunities for researchers to perform many different kinds of photoemission experiments. In this report, the detailed description of the new data acquisition system will be described and the commissioning results will be presented.

## Electron Energy Analyzer

An electron energy analyzer is an essential instrument for an electron spectrometer used in the measurements of electron energy spectra. An electrostatic energy analyzer has from the beginning been adopted for measuring electron energy spectra in surface analysis techniques. This is due to the ease of construction and handling in an ultra high vacuum (UHV) environment, compared to analyzers employing a magnetic field. Among different configurations of electrostatic analyzers, a concentric hemispherical analyzer (CHA) has been proven to be the most suitable for measuring photoelectrons. The best energy resolution of such an analyzer has been improved to the range of a few meV (Kevan, 1983). The CLAM2 energy analyzer used in this work is also an electrostatic CHA.

Figure 1 shows diagrammatically the cross-section of a conventional CHA and the energy diagram when a conducting sample contacts with the CHA. The CHA consists of an electrostatic lens, a hemispherical deflector with entrance and exit slits, and an electron detector, which may be a channeltron or a microchannelplate electron detector. The hemispherical deflector of the analyzer consists of two concentric hemispherical electrodes with the inner and outer hemisphere of radii $R_1$ and $R_2$, respectively. The inner and outer hemispheres are applied with potentials $V_1$ and $V_2$, with $V_1$ greater than $V_2$. For the CLAM2 analyzer, the potentials applied to the inner and outer spherical sectors are the same magnitude but with different polarity. The potential of the outer spherical sector is negative with respect to the inner one, i.e. $V_2 = -V_1$.

The potential *V(r)* along the equipotential surface between the two hemispheres with radius *r* can be obtained by solving the Laplace,s equation in spherical coordinates (Kenneth, 1998). The potential *V(r)* is given in Eqn. (1).

$$V(r) = V\left(R_{av}\right) + 2k_R\left(\frac{R_{av}}{r} - 1\right)\Delta V \qquad (1)$$

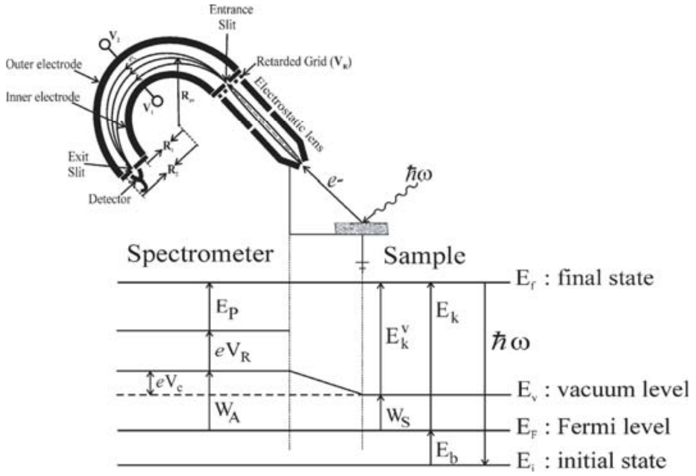

**Figure 1. A schematic diagram showing a cross-section of a conventional CHA. The figure also shows the energy levels when a metallic sample contacts with the CHA**

where $R_{av}$ is the median radius ($R_{av}$ is 100 mm for CLAM2), $k_R$ is the analyzer constant ($k_R = \frac{R_1R_2}{R_2^2 - R_1^2}$), $\Delta V$ is the potential difference between the inner and outer hemispheres, and $V(R_{av})$ is the potential along the median surface, which is given by

$$V(R_{av}) = k_R \Delta V \qquad (2)$$

If photoelectrons with the kinetic energy $E_P = eV(R_{av})$ enter the analyzer at the center of the entrance slit within a small cone around the normal angle, they will travel along the median equipotential surface and pass through the exit slit. Such kinetic energy $E_P$ is called the pass energy. Electrons with kinetic energy higher than $E_P$ are deflected to $E_P$ hit the outer spherical sector while those with kinetic energy lower than hit the inner spherical sector. $E_P$ can be rewritten as given in Eqn. (3).

$$E_P = ek_R \Delta V \qquad (3)$$

For a given analyzer, the pass energy of the analyzer is a function of the potential difference between the inner and the outer hemispheres.

The photoelectrons emitted from the conducting sample are focused in to the entrance slit of the analyzer. Before entering the entrance slit the photoelectrons are decelerated or accelerated by the potential of $V_R$. The photoelectrons with appropriate kinetic energy $E_k$ according to Eqn. (4) will travel passing through the exit slit. The numbers of the photoelectrons are then counted by the detector located at the exit slit.

$$E_k = eV_R + E_P + W_A \qquad (4)$$

where $W_A$ is the work function of the analyzer. Generally, energy analyzers can be operated in two energy analyzing modes, i.e. a constant analyzer energy (CAE) mode and a constant retard ratio (CRR) mode. The CAE mode is normally used for photoelectron measurements such as UPS, XPS, and synchrotron light photoemission. In this mode, the energy spectra are obtained by varying $V_R$ while the pass energy is fixed. To obtain spectra in the CRR mode, $E_P$ is varied with $V_R$ in such a way that the ratio between $V_R$ and $E_P$ is kept constant. The CRR mode is normally used for AES measurements.

In some applications, the binding energy, $E_b$, is referred. The relation between the binding energy and the kinetic energy is given in Eqn. (5).

$$\hbar\omega = E_k + E_b + W_A \qquad (5)$$

## Design Considerations

The existing spectrometer employing the CLAM2 energy analyzer has been designed only for UPS, XPS, and AES measurements. The Thermo VG Scientific VGX900 software was supplied by the manufacturer of the analyzer for data collection and data analysis. The software has been developed for measurement techniques using laboratory excitation sources, thus only the energy distribution curve (EDC) can be obtained. In the EDC mode, the intensity of photoelectrons is measured as a function of their kinetic energy measured at fixed excitation photon energy. Moreover, the software employs rather out-of-date ISA-bus computer-interfacing hardware. In the design of a new data acquisition system, the following considerations have been taken into account.

First, the new system should provide different modes for measuring photoelectrons to take advantage of a tunable synchrotron light source. Photons from the BL4 beamline can be selected between 20 - 240 eV. This opens the opportunity to measure photoelectrons in two new modes of measurement other than the EDC mode, i.e. CIS (constant initial state) and CFS (constant final state) modes. In the CIS mode, the intensity of photoelectrons excited from a given binding energy is measured as a function of the excitation energy of photons. While in the CFS mode, the intensity of photoelectrons with a given kinetic energy is measured as a function of the excitation energy of photons. A total yield of photoelectrons emitted from the sample as a function of photon energy should also be measured. Second, all existing control electronics for the CLAM2 spectrometer must be employed in the new system. Thus a minimum amount of new hardware should be added. In fact, only the out-of-date interfacing card is replaced by a new PCI interfacing card. Finally, the new software should have a user-friendly interface feature.

## System Design

Figure 2 shows the schematic diagram of a new data acquisition system using the CLAM2 spectrometer installed at the experimental station of the BL4beamline. The newly home-developed software has been written using the LabView program of the National Instrument (NI) running under the Microsoft Window 2000 operating system. Only one personal computer is employed to control the monochromator of the beamline, the CLAM2 spectrometer and the pico-ampmeters. RS232C interfacing protocol is used for the communication between the computer and the control electronics of the monochromator, i.e. the controller of the stepmotors and the linear encoder. A PCI GPIB interface card is used for communicating with the pico-ampmeters. An NI PCI-6052E interface card is used for the communication between the computer and the SCU362 spectrometer control unit of the CLAM2 spectrometer. One of the analog inputs of the NI PCI-6052E card is also used for receiving the electron beam current in the storage ring of the light source. This beam current is used for normalization of the acquired data because the electron beam current decreases with time. In addition, the monochromatized photon flux is also monitored by measuring the photocurrent emitted from the gold mesh located in front of the sample. The total electron yield emitted from the sample can also be measured. Two picoampmeters connected to the computer via GPIB-bus are used for measuring the photocurrent of the mesh and the sample.

The new data acquisition system controls the CLAM2 analyzer via the SCU362 spectrometer control unit. Five digital outputs from the NI PCI-6052E interface card are used for selecting the energy range of the analyzer, the energy analyzing modes (CAE or CRR modes) and the pass energy. One analog output (0 - 10 V) from the same interface card is used for controlling the retarded potential. One of the four counters of the interface card is used for counting the signals from the channeltron, representing the number of the detected photoelectrons passing through the exit slit of the analyzer.

Figure 3 shows the wiring diagram between the interface card and the SCU362 unit. The CAE/CRR signal is used for selecting the energy analyzing mode. When the CAE/CRR is in a high status (+5 V), the analyzer is operated in the CAE

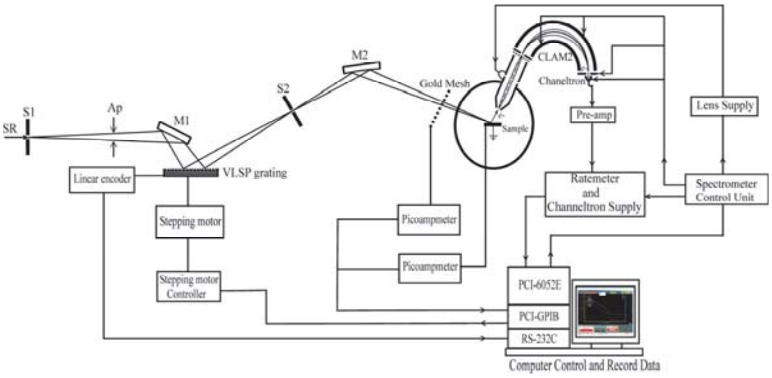

**Figure 2. The schematic diagram of the new data acquisition system for angle-integral photoemission system of the BL4 beamline at the Siam Photon Laboratory**

mode. For the CRR mode, the CAE/CRR is in a low status (0 V). The status of the other four TTL signals are used for the settings of the energy range, the pass energy (or the CAE value), and the CRR values.

When the analyzer is operated in the CAE mode, the 0 - 10 V analog signal is used to provide suitable retarded voltage to allow the electrons with required kinetic energy to pass through the analyzer. In the CRR mode, however, the pass energy is varied with the retarded voltage to keep a constant ratio between the pass energy and the kinetic energy of the detected electrons, and thus to keep a constant transmission across the energy range.

The new data acquisition system supports different measurement techniques, i.e. UPS, XPS, AES, and SL-PES (photoelectron spectroscopy using synchrotron light). For UPS, XPS, and SL-PES, the CLAM2 analyzer is operated in CAE mode, while in AES measurement, the analyzer is operated in the CRR mode. Only the EDC measurement mode is employed for UPS, XPS, and AES measurements because the energies of the excitation photons are fixed. When synchrotron light is used in photoemission measurements, different modes of measurements such as EDC, CIS, and CFS modes can be performed without or with a simultaneous total-yield measurement.

## Results

The calibration of the kinetic energy of measured electrons has been performed using standard gold and copper samples. Table 1 shows the binding energies of core electrons of copper and gold, and the kinetic energy of Cu $L_3MM$ Auger electrons used as the reference in the energy calibration of the CLAM2 spectrometer. From Eqn. (4), the kinetic energy of electrons that can pass through the energy analyzer is a linear function of the retarding voltage. For the CLAM2 spectrometer, the retarding voltage is controlled by the 0 - 10 V analog signal driven by the NI PCI-6052E interface card. Figure 4 is the calibration curves showing the relation between the kinetic energy of electrons measured by the CLAM2 spectrometer and the control voltage of the NI PCI-6052E card for different energy ranges. Mg $K_\alpha$ radiation0 ( $\hbar\omega$= 1,253.6 eV) has been used for the excitation in the calibration procedure. The work function of the spectrometer, claimed by the manufacturer, is 4.2 eV. This value is confirmed by measuring photoelectrons near the Fermi edge of gold using He I radiation ( $\hbar\omega$= 21.2 eV) for the excitation, as shown in Figure 5.

The new data acquisition has been tested by taking spectra in different modes of measurement. The results are shown in Figures 6-8. Figure 6 shows XPS spectra taken from copper and gold samples using Mg $K_\alpha$ radiation. Figure 7 is an AES spectrum taken from a cleaned Cu sample using 5 keV electrons for the excitation. Figure 8 shows CIS and drain current spectra of a clean Ni(111) using synchrotron radiation with photon energy varied from 50 to 160 eV. The CIS spectrum is the height of the 6 eV satellite peak as a function of photon energy. The drain current is taken from the gold mesh located in front of the sample.

**Table 1. The binding energies are used as the reference in the energy calibration of the CLAM2 spectrometer**

| Peak | Binding energy (eV) |
|---|---|
| Cu 2p3/2 | 933.00 |
| Cu L3MM | 334.94 |
| Cu 3p3/2 | 75.00 |
| Au 4f5/2 | 75.00 |
| Au 4f7/2 | 84.00 |

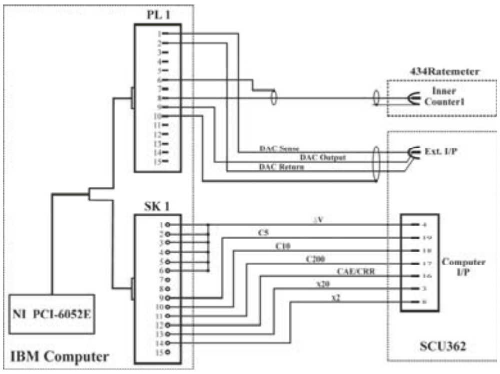

**Figure 3. The wiring diagram connection between the NI PCI-6052E interface card and the SCU362 unit for an analyzer operating in CAE/CRR modes**

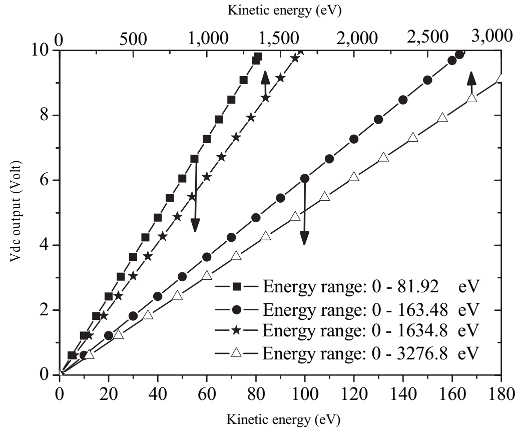

**Figure 4. Calibration curves between electron kinetic energies and the DC voltage supplies to spectrometer Control Unit in UPS, XPS and AES**

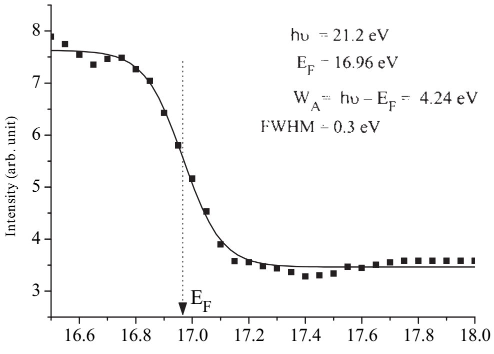

**Figure 5. UPS spectrum of Au near the Fermi edge is measured by the CLAM2 analyzer using home developed data acquisition software and setting the pass energy as CAE10. The UV light source utilized is a He discharge lamp (He I 21.2 eV) at room temperature**

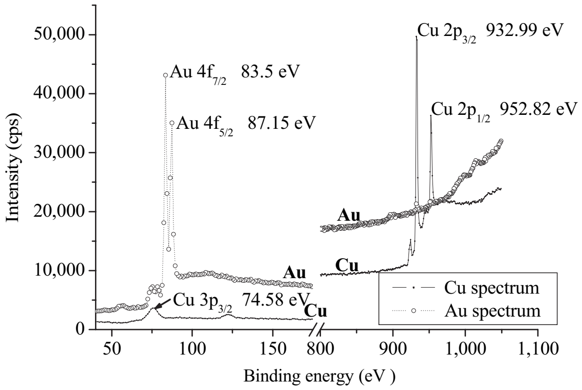

**Figure 6. XPS spectra of Cu and Au are measured by the home developed data acquisition with Mg $k_\alpha$ radiation excitation**

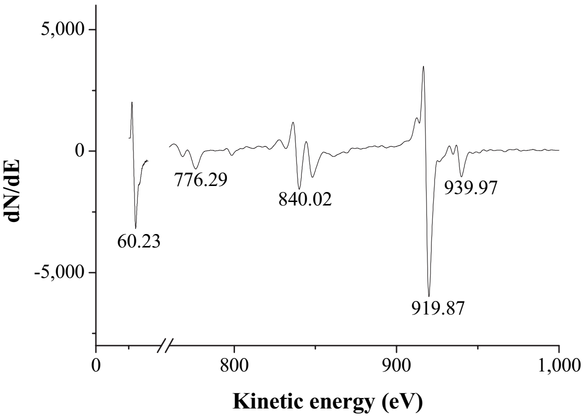

**Figure 7. AES spectrum of Cu is measured by the CLAM2 analyzer using the home developed data acquisition system with 5 keV of electrons for excitation**

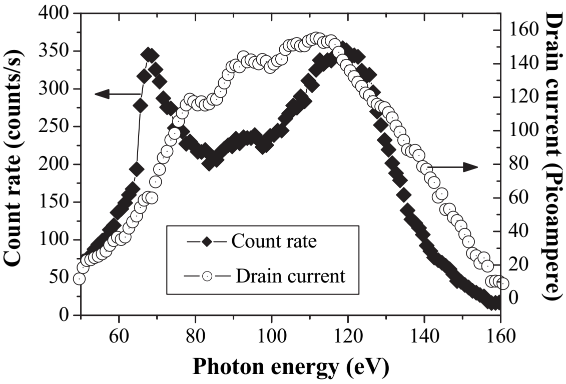

**Figure 8. The CIS and drain current spectra of a clean Ni(111) are measured by the home developed data acquisition system using synchrotron radiation with photon energy varied from 50 eV to 160 eV.**

## Conclusions

A new data acquisition system for angle-integrated photoemission spectroscopy has been developed. The system provides the possibility to perform electron spectroscopic measurements using synchrotron light with different modes of measurement such as EDC, CIS, and CFS. Total yield can also be measured. This new feature of the data acquisition system will allow us to carry out resonant photoemission experiments. The EDC mode of measurement is also used with laboratory excitation sources such as a UV lamp, an X-ray source, and an electron gun for UPS, XPS, and AES measurements, respectively.

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