

DOE EPSCOR FINAL REPORT

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Clean surfaces and those with adsorbates have been investigated to obtain electronic and atomic structure data. The various modes of synchrotron radiation (SR) photoemission spectroscopy (PES) have been performed mostly beam line 7.0.1 at the Advanced Light Source (ALS) in Berkeley, CA and some at the Synchrotron Radiation Center (SRC) in Madison, WI. These were done on silicon, carbon, and group III nitrides.

The (111) oriented Si have several families of vicinal surfaces. It had been established that Au would form one atom chains. It was thought that such quasi one dimensional (1D) structures would show novel quantum behavior. When electrons are confined to reduced dimensions their behavior can radically diverge from that of the bulk, often resulting in exotic phenomena such as the formation of charge and spin density wave, Mott-Hubbard insulators, divergence from Fermi liquid behavior and quantum confinement. Some very speculative memory applications have been suggested. The post-doctoral associate (Jessica McChesney) who joined the group had investigated many of these surfaces in her thesis work. The 1D energy bands due to surface chains were found in several cases, some of which had been reported previously.

A focused effort was to compare Pt adsorption to Au adsorption since the atoms are about the same size and have similar electro negativity, but Pt has one missing d

electron whereas Au-d bands are filled with a binding energy of about 2 eV. The Si (5 5 12) vicinal was used which is cut close to 24 degrees from the (111) toward the $[-1 -1 2]$ and cleaned by the standard treatment. About 0.15 monolayers of Au produced the previously obtained Si(337)-Au chain surface. In the case of Pt a nominal 337 surface is observed which with just a “right” coverage a (11 11 27) Pt surface forms. These surfaces are all very near to 24 degrees so the different induced reconstruction can form. Platinum similar Au induces an ordered surface where the angle resolved PES shows metallic chain-like bands but the structures are very different. The Pt surface forms nano (111) steps with an edge that is in the (001) orientation. These data and STM results lead to the proposal that Pt sits on the (001)-like edges where as Au sits on the (111)-like terraces/steps. These phenomena are attributed to a difference in d electron behavior.

Electron diffraction is in the PES process hence angle resolved photoemission data contain atomic structure information. It was recognized about 20 years ago that the emission is internal reference beam holography and the data could be inverted to obtain an image. In the early nineties we experimentally verified this by obtaining single-atom images for adsorbates on Si surfaces. Considerable effort was made to do such measurements on these chain systems. [GaN were also examined .] STM data show the 1D behavior but cannot identify the atomic species. Hence an image would be very important. Theory has provided some insight.

The experimental data turned out to be very difficult to analyze because the Scienta electron spectrometer which is otherwise a marvelous instrument has a weakness.

The detector is rather non-linear so relative intensities are difficult to determine. As a consequence we did not have confidence in our images. Our efforts show that the experiment should work if good intensity measurements were achieved. (This is not an issue for band mapping.)

Spintronics is a very interesting concept. We have closely followed Chris Palmstrom's group efforts. They are able to find growth parameters for Fe-GaAs junctions where spin injection was achieved. For a long time the feeling was that it would not work. Beam line 7.0 in addition to the photoemission branch has, a branch for SR induced fluorescence. Such a photon-in, photon-out spectroscopy is interesting because the photon inelastic scattering length is very long and buried layers can be probed. Measurements were made on as-grown junction devices. Palmstrom provided samples grown in a device-grade environment for which spin injection data had been measured.

Several types of fluorescence data may be obtained. The basic mode is to collect as much radiation as possible and obtain the fluorescence yield (FY) curve. This can be done for various angles for some depth resolution. [The total electron yield (TEY) can also be measured but the escape depth is shorter.] The fluorescence can also be analyzed with a monochromator to obtain photon energy-resolved fluorescence spectra, either on or off resonance. This spectroscopy is often called RIXS, resonant inelastic x-ray scattering. The latter is very low signal method and needs the high flux of an insertion device like beam line 7.0. The L edge of Fe was measured at about 710 eV. Shoulders and pre-edge features which correlates with the different spin level injections. The effects

could be useful for junction characterization. Inference about bonding configuration was not obtained.

In the beginning we wanted to investigate the properties of GaN and soon learned that the sample qualities available were not of the quality needed for reliable results. This was particularly true for electron diffraction. After a while we abandoned the effort. Eugen Trifan, a post-doctoral associate, was on this program for about a year.

With other funds a Scienta SPS 200 mm electron-energy analyzer was obtained. It was taken with a small analysis chamber and manipulator to ALS for a work station. After discussion, it was decided that the unit would be used for the small spot PES system under development at that time and that we would use the existing unit. Our post-doctoral associate at this time was Aaron Bostwick and he transferred to the ALS effort. The program required a lot of development, but is now making interesting measurements.

Near the end of Jessica McChesney's appointment we phased into the projects taken up by the beam line 7.0.1 staff, namely Graphene investigations. It is one layer of C atoms in the graphite structure with very interesting transport and electronic properties. Before the discovery of how to obtain samples much theoretical results existed because of its close connection with nanotube research. Hence, the field moved quickly.

Several other activities with smaller scope were carried out. One was the further analysis of the holographic method with calculations using our simulation program.

Another is a core level resonance in compound semi-conductors. The PI, after he retired from teaching, wrote several history articles resulting from an invited presentation at Professor William Spicer's memorial at the Stanford Light Source users' meeting.

Prof. Mary Keeffe of Carroll College worked on various parts of the program. The college is an undergraduate institution in Helena MT.

Publications:

A. Bostwick, T. Ohta, J.L. McChesney, K.V.Emtsev, Th. Seyller, K. Horn, E. Rotenberg, Symmetry Breaking in Few Layer Graphene Films, *New Journal of Physics*.

A. Bostwick, T. Ohta, J.L. McChesney, Th. Seyller, K. Horn, E. Rotenberg, Renormalization of graphene bands by many-body interactions, *Solid State Communications*, 143, 63-71, 2007.

V.W. Brar, Yuanbo Zhang, Yossi Yaron, A Bostwick, T. Ohta, J.L. McChesney, K. Horn, E. Rotenberg, M.F. Crommie, Scanning tunneling spectroscopy of inhomogeneous electronic structure in monolayer and bilayer graphene on SiC., *Applied Physics Letter* 91, 1221202, 2007.

T. Ohta, A. Bostwick, J.L. McChesney, Th. Seyller, K. Horn, E. Rotenberg, Interlayer interaction and electronic screening in multilayer graphene investigated with angle-resolved photoemission spectroscopy, *Physical Review Letters*, 98, 206802, 2007.

G.J. Lapeyre, An account of the initial integration of photoemission and synchrotron radiation, *Journal of Electron Spectroscopy and Related Phenomena*, 144, 675, 2005.

Manuscripts to be published:

G.J. Lapeyre, A history of UV photoelectric emission from solids, to be published.

J.L. McChesney, A. Bostwick, F.J. Himpsel, E. Rotenberg, G.J. Lapeyre, Pt induced surface states on Si(337), to be published.

J.L. McChesney, C. Adelman, Per-Anders Glans, Jinghua Guo, C.J. Palmstrom, G.J. Lapeyre, Buried iron films investigated with energy resolved fluorescence, to be published.

H. Wu and G.J. Lapeyre, Properties of the small cone method for measuring photoelectron holographic atomic images, to be published.