MASTER

DOE/ER/10464-2

**The Study of Electrons Photoemitted
from Field-Emission Tips**

Progress Report for Period

July 1, 1980 - January 1, 1981

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**R. Reifenberger
Purdue University**

January 1981

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ABSTRACT

Photo-induced field emission is a technique which studies electrons that have been photoemitted from a field emission tip. This new experimental method promises to combine the proven utility of both field emission and photoemission for investigating the electronic states near a metal surface. The primary objective of the research being performed is to investigate photo-induced field emitted electrons using a tuneable cw dye laser. To fully exploit this continuously tuneable photon source, a differential energy analyzer has been constructed to allow energy resolved measurements of the photo-field emitted electrons. This report describes the progress made in implementing experiments on photo-induced field emission from July 1980 to January 1981.

I. INTRODUCTION

This report describes the progress that has been achieved during the past year on scientific research funded by the United States Department of Energy under Contract No. DE-AC02-79ER10464.A001 entitled "The Study of Electrons Photoemitted from Field Emission Tips". This work has been undertaken to investigate the physical consequences of illuminating field emission tips with intense laser radiation obtained from a tuneable dye laser.

Substantial progress has been made since July 1980 in the assembly and testing of a new stainless steel ultra-high vacuum (UHV) chamber which was ordered in July 1980. This chamber will significantly increase the flexibility of the experiments to be performed. The initial checks made on the ultimate vacuum obtainable in this system have proved very close to the design specifications. While waiting for delivery of the UHV chamber and associated UHV hardware, an effort was made to develop a theoretical framework to allow a ready interpretation of the data to be acquired. This effort has produced very encouraging results which are adequately detailed in a paper entitled "Numerical Transmission Probabilities and the Oscillatory Photo-Induced Field Emission Current: Static and Dynamic Image Charge Effects" which has recently been submitted for publication in Surface Science.

The experiments which we expect to initiate before July 1981 are essentially the same as those proposed in last years' renewal proposal. The exact nature of these experiments will be discussed more thoroughly in the renewal proposal for 1981-1982. Briefly the experiments will be concerned with measurements of the total energy distributions of photo-excited field emitted electrons from molybdenum and rhodium and measurements of the electric field dependence of the photo-field current. Equipment has been

constructed to search for the laser-induced diffusion of alkaline adsorbate atoms deposited on field emission tips but progress in implementing these experiments has been hindered due to manpower limitations.

The remaining sections of this report describe the progress made since July 1980 in implementing research on photo-induced field emission. In addition, factual summaries which are deemed relevant to this work are also provided when necessary. It is also worth noting that Secs. IV, V and VI are included for the sake of completeness even though they describe progress which did not technically occur since July 1980.

II. FACTUAL INFORMATION

A. Personnel Involved

<u>Name</u>	<u>Title</u>	<u>Period of Support</u>	<u>Percent Effort</u>
R. Reifenberger	Principal Investigator	7/1/80-6/30/81	10%-DOE Contribution 15%-Purdue U. Contribution
D. L. Haavig [†]	Graduate Student	7/1/80-6/30/81	3/4 time
C. Egert [*]	Graduate Student	7/1/80-6/30/81	3/4 time

[†]Ph.D. Thesis Topic: "Effects of Bulk Band Structure on Photo-Induced Field Emission from Mo and Rh".

^{*}Ph.D. Thesis Topic: "The Electric Field Dependence on the Photo-Induced Field Emission Current from Mo".

B. Expenditures by Categories

for period

July 1, 1980 through January 1981

	1/7/80 Initial Budget	1/12/81 Unencumbered funds	6/30/81 Estimate of funds at end of present contract period
Salaries and Wages	\$15,395	\$ 8,964	~ 0
Indirect Costs	10,715	6,239	~ 0
Supplies and Expenses	13,548	~ 1,550	~ 0
Equipment in Excess of \$1,000	<u>20,730</u>	<u>4,300</u>	<u>~ 0</u>
Total	\$60,388	\$21,053	~ 0

^{*} ~ 65% of award has been expended or encumbered.

III. CONSTRUCTION AND TESTING OF ULTRA HIGH VACUUM STATION

A stainless steel, ultra high vacuum (UHV) station, suitable for experiments on photo-induced field emission has been designed. The chamber was constructed from 304 stainless steel by Thermionics, Inc. and was received in our laboratory in late September 1980. A Cryo-Torr ultra high vacuum cryopump made by CTI-Cryogenics was ordered to pump the stainless steel chamber to pressures in the mid 10^{-10} Torr range. A schematic of the chamber is shown (without cryopump) in Fig. 1. Initial tests of the chamber were performed in December 1980 and pressures of $\sim 9 \times 10^{-10}$ Torr were obtained within a few days after the initial evacuation of the chamber, thereby indicating the suitability of the apparatus for the purposes in mind.

A significant feature of the UHV chamber is the precision XYZ manipulator which will allow for the exact positioning of the field emission tip with respect to the energy analyzer. In addition, the manipulator is equipped with a 360° rotator that will easily permit different facets of the same field emission tip to be illuminated by the intense radiation of the focused laser beam. This feature is a significant experimental advance over all previous experiments which have been done on photo-induced field emission. By including such flexibility in the design of the UHV chamber, important experiments concerning the anisotropy in the photo-field current can now be routinely contemplated and performed.

Figure 1. A schematic of the UHV stainless steel chamber showing the XYZR precision manipulator, the experimental chamber complete with quartz window (Q) and viewport (V), and the feedthru collar which rests on the UHV cryopump (not shown).

IV. ENERGY ANALYZER

The assembly of the energy analyzer which was designed and constructed in 1979-1980 has been accomplished with no significant problems to date. A scaled drawing of this energy analyzer is shown in Fig. 2.

The energy analyzer consists of four spherically concentric plates centered in front of the tip. The potential on the plate closest to the tip has a potential of about 2000 volts positive relative to the tip. The surface of the first spherical plate facing the tip has a phosphor coating so that the symmetry of the field emission pattern can be observed and used as a guide for selecting electrons emitted from high symmetry directions. A small probe hole in the center of the first plate permits the electrons from the crystallographic plane positioned over the probe hole to pass through.

The other three plates make up a retarding potential energy analyzer and also have probe holes to pass electrons. The plate furthest from the tip is set at a constant positive voltage which is slightly greater than the potential applied to the tip. The potentials on the middle two plates are adjusted to maintain a spherically symmetric electric field along the electron's path. The electrons emerging from the hole in the last plate enter a 127° velocity selector; the electrons which leave the velocity selector have a known velocity and thus a known energy. These electrons pass through a two element einzel lens and then through deflector plates so that they may be directed onto the spiraltron electron multiplier. This multiplier, when properly biased, has a gain of about 10^{+6} . The resulting electrons are then collected on a plate located immediately behind the spiraltron. The output signal from the collector plate consists of short, negative-going pulses which are directed to a data acquisition system for further analysis.

Figure 2. The energy analyzer which has been constructed consisting of the field emission tip assembly (A), the spherical retardation electrodes (B), 127° velocity selector (C), Einzel lens and deflection electrodes (D), spiraltron electron multiplier (E) and output signal lead (F). The supporting electrodes and electrical feedthrus have been omitted for the purposes of clarity.

The energy of the electrons being collected at the spiraltron is determined by the potentials on the velocity selector. The energy (in eV) of these electrons is given by

$$\text{K.E.} = \Delta V / [2 \ln(b/a)]$$

where ΔV is the difference in potential between the outer and inner cylindrical walls with b and a as their respective radii. As is well known, two electrons with the same speed entering the cylindrical field at small angles normal to the field will be focussed after traversing an angle of $127^\circ 17'$.

The tip is mounted on a precision manipulator attached through a flexible bellows to the main body of the UHV chamber. The bellows allow for an adjustment of the tip for centering, and two sets of electrostatic deflection plates surrounding the tip allows a fine adjustment of the field emission pattern over the probe hole.

V. DATA ACQUISITION AND ANALYSIS

The data analysis is centered around a versatile MINC 11 minicomputer system. The system, specifically designed for interaction with experimental apparatus, is shown schematically in Fig. 3.

The pulses from the experiment are pre-amplified, sent through a discriminator, then amplified and shaped into square pulses. These pulses can be counted externally or internally by the MINC 11; if the pulses are counted externally, the data can be loaded into the MINC 11 through a digital input interface.

Once the MINC 11 has the data it can be saved on a floppy disk for later analysis, analyzed and plotted on the video graphics terminal, plotted on the hard copy plotter, or listed on the decwriter printer. At the present time, a program is being written to take advantage of the interrupt capabilities of the MINC 11 computer, which will allow all of these devices

Fig. 3: The data acquisition and analysis system.

listed above to be used simultaneously. This includes the capability of performing complicated numerical analysis of data while more data is being acquired. Since a modem is connected to the MINC 11, the data may be sent to the CDC computer in the main computer center here at Purdue University for additional analysis.

Through a digital output interface, the MINC 11 can adjust the voltages on the velocity selector, control the counters and timers used, and activate other devices that may be added in the future.

VI. LASER FACILITY: CAPABILITIES

Useful photon excitation energies for photofield emission experiments would range from about 1.5 eV to 4.5 eV. This range of energies cover light frequencies from the near infrared to the near ultraviolet.

To investigate how the experimental results depend on excitation energy several energies must be available in the range stated above. This is accomplished by using a dye laser with different dyes which allows a continuous sweep of photon energy over a limited range of energy.

Permission has been given for the use of the NSF-MRL Central Laser Facility at Purdue University. A Coherent Radiation CR-10-U Ar⁺ ion laser will be used to pump a newly purchased Spectra Physics Model 375 Dye Laser. Several dyes will be used that will produce photon energies in the range of 1.9 eV to 3.1 eV. Typical output power of about 1/2 watt will result.

In addition to the argon ion laser, the NSF-MRL Central Laser Facility also has a Kr⁺ laser (Spectra Physics Model 171) which in principle is available for use. Although no plans are made for the use of this laser, it does offer the possibility of expanding measurements of photo-induced field emission into the near infrared region of the electromagnetic spectrum should the need arise.

A summary of the available range of photon energies which are in principle accessible for this experiment is provided in graphical form in Fig. 4.

VII. THEORETICAL DEVELOPMENTS

During the period of time from July to mid-October 1980 during which we were waiting for the delivery of the UHV system, considerable effort was expended on calculations which could be readily used in interpreting experimental data that will be obtained. The results of these calculations are adequately presented in a paper entitled "Numerical Transmission Probabilities and the Oscillatory Photo-Induced Field Emission Current: Static and Dynamic Image Charge Effects" which has been recently submitted to Surface Science for publication. A copy of this paper is included as an Appendix in this report.

In this paper, we describe our numerical calculation of the transmission probability of electrons to escape from a metal surface which is subjected to an applied electric field. The calculation can be done exactly only for the case in which the image charge potential is neglected. If the image charge is included, the problem must be solved numerically by integrating Schroedinger's Equation using appropriate algorithms and specifying the form of the potential barrier which an electron must overcome in escaping from the metal.

The one dimensional model potential which was used in Schroedinger's Equation is given by

$$V(x) = -eFx - \frac{e^2}{16\pi\epsilon_0 x}$$

in which the first term represents the potential due to an applied electric field of strength F and the second term is the well known static image

Fig. 4: A plot of typical output power vs wavelength (or energy) of Spectra Physics dye laser using 5 dyes as labelled. Also shown are the single lines available from the Argon and Krypton pump lasers which are part of the NSF-MRL Central Laser Facility at Purdue University.

charge correction. Transmission probabilities $D(W,F)$ and wave functions $\psi(x,F,W)$ which describe the escaping electron for a specified electric field F and energy W (measured with respect to the vacuum level) have been calculated (see typical results given in Fig. 5). These calculations can be easily extended to incorporate other forms of $V(x)$ than that given above.

From a practical point of view, calculations of $D(W,F)$ have been performed for 151 different electric field strengths between 5×10^8 V/m and 4.3×10^9 V/m, a range of electric fields which are deemed relevant to photo-induced field emission. These results have been stored permanently on a floppy disc in our minicomputer system (see Sec. V of this report) and will allow ready comparison of experimental data to realistic theoretical calculations while the data is being obtained. Such on line comparison between theory and experiment is expected to greatly improve our understanding of the photo-field emission process.

From a first principles theory point of view, our calculations have questioned the usefulness of the static image potential given in $V(x)$ above. The details concerning this issue are provided in adequate detail in the Appendix and specific experiments to check the validity of these speculations are outlined in the renewal proposal proper.

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Figure 5. A plot of the real (solid line) and imaginary (dashed line) components of the photo-field emitted electrons. The wavefunctions have been superimposed on a plot of the potential barrier used to calculate the wavefunctions shown.