The Study of Electrons Photoemitted
from Field Emission Tips

Progress Report for Period

MASTER

July 1, 1979 - March 1, 1980

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R. Reifenberger

Purdue University

Contract DE-AC02-79ER10464

February 1980

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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 is being 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 1979 to March 1980.

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.A000 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 laser radiation obtained from a tuneable dye laser.

Substantial progress has been made during the past six months in both the design and construction of integral pieces of apparatus that are essential for the upcoming experiments on photo-induced field emission. In addition, the range of proposed research topics discussed in the initial research proposal have been critically scrutinized and efforts are now underway to concentrate on three specific experiments during the next twelve month period. The exact nature of these experiments are discussed more thoroughly in the renewal research proposal. Briefly the experiments will center on measurements of the total energy distributions of photo-excited field emitted electrons from molybdenum and rhodium, measurements of the electric field dependence of the photo-excited current and studies to detect laser induced diffusion of alkaline adsorbate atoms deposited on a field emission tip.

The remaining sections of this report describe the progress made during the past six months in implementing research on photo-induced field emission. In addition, factual summaries which are deemed relevant to this work are also provided when necessary.

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	9/1/79-6/30/80	10%-DOE Contribution 15%-Purdue U. Contribution
D. L. Haavig [†]	Graduate Student	9/1/79-6/30/80	3/4 time
C. Egert [*]	Graduate Student	9/1/79-1/1/80 1/1/80-6/30/80	1/2 time 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, 1979 through June 30, 1980

	<u>1/7/79</u> <u>Initial</u> <u>Budget</u>	<u>2/20/80</u> <u>Unencumbered funds</u>	<u>6/30/80</u> <u>Estimate of funds</u> <u>at end of present</u> <u>contract period</u>
Salaries and Wages	\$10,105	\$ 5,019	~ 0
Indirect Costs	7,033	3,493	~ 0
Supplies and Expenses	11,475	~ 3,000	~ 0
Equipment in Excess of \$1,000	17,150	2,770	~ 500
Total	\$45,763	\$14,282*	~\$500

* ~ 69% of award has been expended or encumbered.

III. CONSTRUCTION AND TESTING OF ULTRA HIGH VACUUM STATION

An all glass, ultra high vacuum station has been constructed which consists of a 3 stage Hg diffusion pump (pumping speed of ~ 70 l/sec) backed by two liquid nitrogen cold traps. A schematic diagram of this apparatus is shown in Fig. 1. By alternately baking cold trap #2 and then cooling it to liquid nitrogen temperatures, the lowest pressure in the pumping system has been measured at $\sim 5 \times 10^{-10}$ Torr as measured by a Bayard-Alpert ion gauge.

Fig. 1: The UHV pumping station consisting of a forepump liquid nitrogen cold trap (A), a 3-stage Hg diffusion pump (B), liquid nitrogen cold trap and heating mantel (C), a second, bakeable liquid nitrogen cold trap (D), a Bayard-Alpert ion gauge (E), oven and heating elements (G) and the experimental apparatus (F).

IV. DESIGN AND CONSTRUCTION OF ENERGY ANALYZER

Considerable effort has been expended in designing the experimental energy analyzer to be used in these experiments. A scaled drawing of this energy analyzer enclosed in a specially designed glass tube 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 will have 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 emission from the tip 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 tube consists of short, negative-going pulses which are directed to a data acquisition system for further analysis.

Fig. 2: The photo-field emission tube under construction consisting of a reentrant dewar and flexible bellows (A), field emission tip assembly (B), quartz windows (C), spherical retardation electrodes (D), 127° velocity selector (E), einzel lens and deflection electrodes (F), spiraltron electron multiplier (G) and output signal lead (H). The supporting electrodes and electrical feed throughs have been omitted for 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. It was shown by Hughes and Rojansky that 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 $127^\circ 17'$.

At the top of the tube, the tip is mounted on a re-enterant dewar attached through a flexible bellows to the main body of the tube. 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.

All major design work has been completed on the energy analyzer at the time of this writing. Also $\sim 90\%$ of the machine shop work necessary to build the analyzer has been completed. It is anticipated that the actual assembly of the energy analyzer will be completed during the next two to three months without any great difficulty.

After assembly, two major tasks must be completed before actual experimental work can begin. The speed with which these tasks are completed may likely determine the time scale for the completion of all further experimental work. The first critical task involves sealing the energy analyzer system into a suitable glass tube shown schematically in Fig. 2. The tube must then be attached to the glass pumping station and evacuated to pressures in the 10^{-10} Torr range. The second critical task involves the initial testing of the energy analyzer system. This will be done by measuring the

field emission energy distribution of electrons field emitted from a suitable tip. This task involves not only a test of the electron optics but also of the minicomputer system which will be used to acquire and analyze the data obtained in the photo-field experiments.

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 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.

Fig. 3: The data acquisition and analysis system.

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 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 available in this work is provided in graphical form in Fig. 4.

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.

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2. Contract No.		
4. Type of Document ("X" one) ☐ a. Scientific and technical report ☐ b. Conference paper: Title of conference _____ Date of conference _____ Exact location of conference _____ Sponsoring organization _____ ☒ c. Other (Specify Thesis, Translations, etc.) Progress Report		
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8. Submitted by R. Reifenberger/Assistant Professor of Physics Organization Purdue University; Physics Department Signature R. Reifenberger		Date February 25, 1980

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8. Submitted by R. Reifenberger/Assistant Professor of Physics	Name and Position (Please print or type)
Organization Purdue University; Physics Department	
Signature R. Reifenberger	Date February 25, 1980

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9. Patent Clearance ("X" one)
☐ a. DOE patent clearance has been granted by responsible DOE patent group.
☐ b. Report has been sent to responsible DOE patent group for clearance.
☒ c. Patent clearance not required.

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1. DESCRIPTIVE TITLE OF WORK <p style="text-align:center">The Study of Electrons Photoemitted from Field Emission Tips</p>					
2. PERFORMING ORGANIZATION CONTROL NUMBER <p style="text-align:center">DSP # 1654</p>		3. CONTRACT, GRANT OR PURCHASE ORDER NUMBER <p style="text-align:center">DE-AC02-79ER10464, A000</p>			
4. CONTRACTOR'S PRINCIPAL INVESTIGATOR/PROJECT MANAGER AND ADDRESS WHERE WORK IS PERFORMED (317) a. NAME (Last, First, MI) <u>Reifenberger, Ronald G.</u> PHONE <u>493-9318</u> b. BUSINESS ADDRESS: STREET <u>Purdue University, Physics Department</u> CITY <u>W. Lafayette</u> STATE <u>IN</u> ZIP <u>47907</u>					
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7. PROJECT SCHEDULE (a) START DATE <u>July</u> <u>1979</u> (b) EXPECTED COMPLETION DATE <u>NA</u> (Month) (Year) (Month) (Year)					
8. a. FUNDING OPERATING AND CAPITAL EQUIPMENT OBLIGATION (In Thousands of Dollars)					
FUNDING ORGANIZATION(S)		APPROXIMATE CUMULATIVE PRIOR FISCAL YEARS	CURRENT FY		
1. DOE		0	\$46,000		
2. Research Corporation		0	10,000		
3.					
b. DOE BUDGETING AND REPORTING CLASSIFICATION CODE _____					
9. DIRECT SCIENTIFIC AND TECHNICAL MANPOWER					
		PROFESSIONAL	GRAD. STUDENTS	OTHER	TOTAL
NUMBER		1	2		3
EQUIVALENT PERSONYEARS		.25	1.5		1.75

DETACH HERE BEFORE SUBMITTING

Photo-induced field emission is a technique which studies electrons that have been photoemitted from a field emission tip. This 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 described in this proposal is to investigate photo-induced field emitted electrons as a function of both their final state energy and the applied electric field by using a tunable cw dye laser. To fully exploit this continuously tunable photon source, a differential energy analyzer is being constructed to allow energy resolved measurements of the photo-field emitted electrons. Other experiments, directly related to the unique effects associated with the illumination of metallic tips by laser light, are also proposed. Experiments will be performed that exploit the large temperature rise of a field emission tip when illuminated by a focussed laser beam to study thermally activated surface diffusion of adatoms on a field emission tip. These experiments may provide information about thermally-induced or laser-induced chemical reactions on small metallic surfaces.

1. We have designed and constructed an all glass, UHV pumping station consisting of a Hg diffusion pump and two liquid nitrogen cold traps. Lowest pressure in blanked off system is $\sim 5 \times 10^{-10}$ Torr.
2. We have designed and machined a differential energy analyzer with a predicted energy resolution of $\sim .03$ eV.
3. We have assembled and interfaced a versatile mini-computer system centered around a Digital Equipment Corporation MINC 11 computer.

F	2									
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photo-field emission
surface potential barrier

3	1	7	4	9	3	9	3	1	8
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Feb. 25, 1980