REQUIRED Cover Page

APPLICATION FOR PROFESSIONAL DEVELOPMENT GRANT

**All applicants please complete this cover page.

Choose one: [ ] Creative activity [X] Research activity [ ] Professional Enhancement activity	**Date of Last PDG Award** (Semester and Year awarded): Never Funded **Date of ATU Faculty Appointment** (Semester and Year): 08-03

1. Project Title: Cross Sectional Scanning Tunneling Microscopy (STM) Studies of Quantum Nanostructures

2. Name of Principal Investigator/Project Director: Dr. Daniel Bullock

3. School (abbrev): PLS **4. Department:** Physical Science (Physics)

5. Campus Mail Address: McEver Hall Room 03 **6. PI/PD Campus Phone:** 968-0230

7. Amount Requested: $ 5,200 **8. Total Cost of Project:** $ 5,200

9. Does this project involve: **10. Duration of Project:** 4 months

5/5 – 1000 spend by June 30 per Bullock

Yes No
- [ ] [X] human subjects?
- [ ] [X] animals/animal care facility?
- [ ] [X] radioactive materials?
- [ ] [X] hazardous materials?
- [ ] [X] biological agents or toxins restricted by the USA Patriot Act?
- [ ] [X] copyright or patent potential?
- [ ] [X] utilization of space **not** currently available to the PI/PD?
- [ ] [X] the purchase of equipment/instrumentation/software currently **available** to the PI/PD?

NOTE: If the answer is "yes" to any of the above questions, the investigator must attach appropriate documentation of approval or justification for use/purchase.

SIGNATURES

Jeff W. Robertson 2006 Apr 26
Department Head **Date**

[signature] 4-28-06
Dean **Date**

This Section to be completed by the Office of Academic Affairs

PDC Committee Award Recommendation: Yes____ No____
PDC Committee Proposal Rank: ______ of _____ Total Proposals.
Recommendation of VPAA: Yes____ No _____
Recommendation of President: Yes____ No _____
Award Date: ____________________

B. ABSTRACT Artificially fabricated semiconductor nanostructures were introduced more than 20 years ago with some spectacular consequences in both basic physics discoveries and in commercial applications.[1-3] Infrared detectors, for example, are now used in both commercial as well as military applications. Quantum dots (QD) are a very specific type of nanostructure that show great promise for the basis of the next generation of advanced "quantum computers". Quantum dots are possible because scientists and engineers have precise, atomic scale control over their synthesis. These structures can be characterized at the atomic scale using a scanning tunneling microscope (STM). Typical STM does not offer the information about the alignment or size of the layered QD arrays. However, cross – sectional STM (XSTM) is a technique that can image the buried layers by examining the cross section of the sample. This project will use XSTM to measure the optical, chemical, and electronic properties of stacked QD arrays.

C. PURPOSE / OBJECTIVES The purpose of this research project is to image quantum dot (QD) arrays using cross-sectional scanning tunneling microscopy (XSTM). Our objective is to correlate the optical and electronic properties of the arrays with different growth parameters (temperature, pressure, atomic ratios, etc.).

D. SIGNIFICANCE / NEED The next generation of nanodevices have amazing capabilities due to the fact that they are constructed using the latest technology in device production. This process gives scientists and engineers atomic-scale control over the growth process. What was lacking until the mid 1980's was a characterization technique that had the same type of precision. Binning *et al.* developed such a tool called the scanning tunneling microscope (STM).[4-8] In STM a very sharp probe, or tip is brought within 5-10 Å (note: 1 Å = 10^{-11} m) of the sample. A bias voltage is applied to the tip and sample. Next, electrons begin to quantum mechanically tunnel from the tip to the sample creating a tunneling current. This tunneling current is exponentially proportional to the distance between the tip and sample. This means that very small changes in the distance will result in large changes to the tunneling current. This sensitivity to changes in distance, or height, is what gives STM the ability to produce stunning, atomic scale images (see Figure 1). Typically, STM is used to measure the topography of the last few layers of deposited (epitaxial) materials. However, these "plan view" images lack information about the layers that are buried epitaxial layers. When studying layered QD arrays, the vertical alignment of these nanostructures have significant effects on their optical and electronic performance, but this information is not available is standard "plan view" STM.[9-11] What is needed is information about the morphology of the interfaces between the stacked layers of QDs. In order to do this we need atomic scale cross – sectional images. A technique known as cross – sectional STM (XSTM) offers this information.[12] XSTM differs from plan view STM in that it gives the user structural and electronic information about the buried interfaces. The cross-sectional technique is significantly more difficult to perform than plan view imaging do to the challenges that must be overcome in preparing the sample. In XSTM, the samples are cleaved (i.e. broken) inside an ultra-high vacuum (pressure ~ 10^{-10} Torr) environment and then imaged on this cleaved surface. In order to obtain an atomic scale image, the induced cleave is of greatest importance. It is necessary to have a cleavage plane that is atomically flat. In order to achieve this, extensive sample preparation is needed. To increase the chances of a good cleave the sample must be thinned to a thickness of ~100 microns (this is equivalent to the thickness of a human hair). This thinning is complicated by the brittle nature of the sample. Silicon based semiconductor materials are generally very stiff but can withstand some aggressive polishing, but the III-V based semiconductors (so called because they come from group III and group V of the period table) that

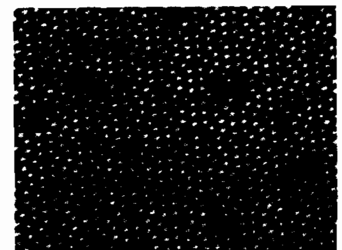

Figure 1 Plan view STM image of Silicon atoms. NOTE: The image scale is 100 nm x 100 nm

are used to make QD arrays are prone to fracturing. Additionally, in order to guide the cleave a small scribe mark must be made on the thinned sample. This 1-2 mm scribe is made using diamond cutting tools. Naturally, if the user applies too much pressure to the thinned sample it will shatter. Finally, if a scientist or engineer has been able to make it past these hurdles without destroying the sample they must mount it in a rigid sample mount that is optimized for cross sectional STM. Fortunately the research team at TECH has been able to solve many of these problems over the past year. Now that we are able to consistently produce atomically flat cleaves we are now ready to implement these preparation algorithms for studying the layered QD arrays.

E. PROCESS FOR ATTAINMENT OF OBJECTIVES / GOALS In order to achieve our goals we will collaborate with the University of Arkansas Nanoscience Center for Materials Research and Engineering (NOTE: The principle investigator and three undergraduate students from TECH have received funding to be supported by the center for the summer). This center has the major equipment needed for our experiments (an ultrahigh vacuum STM, sample growth apparatus, and various characterization techniques). Our QD arrays will be prepared using the center's Molecular Beam Epitaxy (MBE) machine. Fabrication via MBE growth occurs in an ultra-high vacuum (UHV) environment, where molecular beams of group III and group V molecules impinge on a substrate (see Figure 1).[13] In MBE, the mean free path for the impinging flux is much greater than the distance from source to sample, consequently the growth kinetics are determined by the relative sticking coefficients of the two species, by the diffusion rate of the two species once they are in contact with the substrate surface, and by the dissociation rate of the molecules.[14-15] Once samples have been fabricated, we will transfer them from the MBE

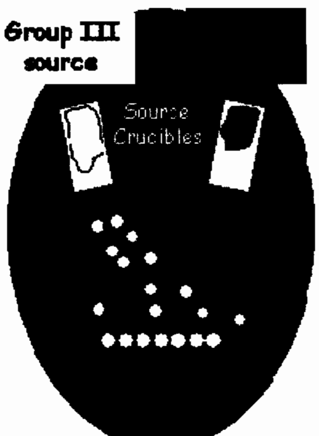

Figure 2 Schematic of a molecular beam epitaxy (MBE).

chamber to our XSTM sample prep station. Here we will first cut our sample to the size needed for the STM sample plate. Next we will mechanically polish our samples from a thickness of 3.5 mm down to a thickness of ~100 microns. After multiple samples have been polished we will place them on our scribe machine. This machine (which was designed and built at TECH) is designed to scribe the 100 micron sample without damaging it. The final step will be to load our sample into the STM chamber and begin taking data. The following Gantt chart gives a timeline for the completion of the goals of this project.

	May	June	July	Aug.
Literature review				
Ordering supplies and materials				
Sample preparation				
XSTM Work				
Paper preparation				
Attend Conference				

F. DISSEMINATION OF RESULTS The results of this project will be prepared in a final report submitted to the Professional Development Grant committee. Additionally, a paper will be prepared and presented at the International Conference on Nanoscience & Technology (ICN+T 2006) in Basel, Switzerland. **This conference has a special workshop on teaching nanoscience in the classroom that I would attend.** Finally, the students involved in this project will present their findings at the Arkansas Academy of Sciences Annual Meeting as well as the Arkansas Tech University Undergraduate Research Symposium.

G. REPEATED REQUESTS The PI for this proposal has never requested funds from the Professional Development Grant program.

H. BUDGET

PROPOSED BUDGET
FACULTY RESEARCH GRANT
(include budget categories as appropriate)

1.	Non-work study stipend	0.00
	Fringe benefits @ .4% (4/10 percent) of non-work study stipend	
2.	*Supplies (please list items to be purchased and estimated price per item including taxes and shipping, if appropriate):	
	GaAs Wafers	500.00
	Gloves	20.00
	Sample Prep. Supplies	480.00
	Total estimated supplies $	**1000.00**
3.	Travel (please list travel expenditures by date and estimated costs):	
	International Conference on Nanoscience & Technology (ICN+T 2006) **NOTE: This conference also includes a special one day seminar titled "Teaching Scanning Probe Microscopy and Nanotechnology"**	600.00
	Flight	1600.00
	Conference Hotel	1200.00
	Food and transportation	800.00
	Total estimated travel $	**4200.00**
	TOTAL PROPOSED BUDGET $	**5200.00**

I. BIBLIOGRAPHY: Provide standard citations for material referenced.

1. *Compound Semiconductor* 4, 25 (1998).

2. *Physics Today* 49, No. 5, 22 (1996).

3. *Materials Research Bulletin* 23, No. 2, 31 (1998).

4. Binnig, G., Rohrer, H., *Helv. Phys. Acta* 55, 726 (1982).

5. Binnig, G, Rohrer, H., Gerber, C., Weibel, E., *Appl. Phys. Lett.* 40, 178 (1982).

6. Binnig, G, Rohrer, H., Gerber, C., Weibel, E., *Phys. Rev. Lett.* 49, 57 (1982).

7. Binnig, G., Rohrer, H., *Surf. Sci.* 126, 236 (1983).

8. Binnnig, G., Quate, C., Gerber, C., *Phys. Rev. Lett.* 56, 930 (1986).

9. M. Migliorato, L. Wilson, D. Mowbray, M. Skolnick, *Jour. Appl. Phys.* 90, 6374 (2001).

10. B. Grandidier, Y. Niquet, B. Legrand, J. Nys., C. Priester, D. Stievenard, J. Gerard, V Thierry-Mieg, *Phys. Rev. Lett.* 85, 1068 (2000).

11. B. Legrand, B. Grandidier, J. Nys., D. Stievenard, J. Gerard, V. Thierry-Mieg., *Appl. Phys. Lett.* 73, 96 (1998).

12. E. Yu, *Chem. Rev.* 97, 1017 (1997).

13. M. Herman, H. Sitter, *Molecular Beam Epitaxy,* Springer; Berlin, Heidelberg (1996).

14. J. Tsao, *Fundamentals of Molecular Beam Epitaxy,* Academic; San Diego (1993).

15. M. Panish, H. Temkin, *Gas Source molecular Beam Epitaxy – Growth and Properties of Phosphorus Containing III-V Heterostructures,* Springer; Berlin, Heidelberg (1993).

J. APPLICATION VITA (maximum: 3 pages)

Daniel Bullock
Assistant Professor of Physics
Arkansas Tech University

i. Professional Preparation

Ph.D.	Physics, May 2001, University of Arkansas
M.S.	Physics, May 2000, University of Arkansas
B.S.	Physics, May 1997, Arkansas Tech University

ii. Appointments

Fall 2003-	Assistant Professor of Physics, Arkansas Tech University
2001-2003	Post Doctoral Research Associate, Department of Physics University of Arkansas
1997-2001	Research Assistant, Department of Physics University of Arkansas

iii. Publications

1. *Speediness and Classroom Response Systems: A Pilot Study,* D. W. Bullock and W. J. Gonzalez-Espada, submitted to Arkansas Academy of Sciences (2006).
2. *Time-evolution of the GaAs(001) pre-roughening process*, Z. Ding, D. W. Bullock, P. M. Thibado, V. P. LaBella, and Kieran Mullen Surface Science, Vol. 540 No.2-3 p. 491 (2003).
3. *Atomic-Scale Observation of Temperature and Pressure Driven Preroughening and Roughening*, Z. Ding, D. W. Bullock, P. M. Thibado, V. P. LaBella, and Kieran Mullen Physical Review Letters, Vol. 90 No. 21 p. 216109 (2003).
4. *Dynamics of Spontaneous Roughening on the GaAs (001)-(2 × 4) Surface,* Z. Ding, D. W. Bullock, W. F. Oliver and P. M. Thibado, Journal of Crystal Growth, Vol. 251 No.1-4 p.35 (2003).
5. *Simultaneous Surface Topography and Spin-Injection Probability,*D. W. Bullock, V. P. LaBella, Z. Ding, and P. M. Thibado Journal of Vacuum Science and Technology B, Vol. 21 No. 1 p.67 (2003).
6. *Mapping the Spin-Injection Probability on the Atomic Scale,* D. W. Bullock, V. P. LaBella, Z. Ding, and P. M. Thibado Journal of Superconductivity: Incorporating Novel Magnetism, Vol. 15, No. 1, p. 37 (2002).
7. *Enhancing the Student-Instructor Interaction Frequency,* D. W. Bullock, V. P. Labella, T. Clingan, Z. Ding, G. Stewart, and P. M. Thibado The Physics Teacher, Vol. 40, p. 535 (2002).
8. *Enabling Electron Diffraction as a Tool for Determining Substrate Temperature and Surface Morphology,*V. P. LaBella, D. W. Bullock, Z. Ding, C. Emery,and P. M. Thibado Applied Physics Letters, Vol. 79, No. 19, p. 3065 (2001)
9. *Spatially-Resolved Spin-Injection Probability for Gallium Arsenide,* V. P. LaBella, D. W. Bullock, Z. Ding, C. Emery, A. Venkatesan, M. Mortazavi, W. F. Oliver, G. J. Salamo, and P. M. Thibado, Science Vol. 292, p. 1518 (2001).

10. *Invited: Union of the Real Space and Reciprocal Space view of the GaAs(001) Surface*, V. P. LaBella, Z. Ding, D. W. Bullock, C. Emery, and P. M. Thibado International Journal of Modern Physics B Vol. 15, No. 17 p. 2301 (2001).
11. *Microscopic Structure of Spontaneously Formed Islands on the GaAs(001)-(2 × 4) Reconstructed Surface,* V. P. LaBella, Z. Ding, D. W. Bullock, C. Emery, and P. M. Thibado J. Vac. Sci. Technol. B Vol. 19, No. 4, p. 1640 (2001).
12. *A Novel STM Imaging Mechanism is Used to Determine the Atomic Structure of the GaAs(001)-(2 × 4) Surface* V. P. LaBella, D. W. Bullock, and P. M. Thibado, P. Kratzer and M. Scheffler Omicron Newsletter 4(2) 4 (2000).
13. *Reflection high-energy electron diffraction and scanning tunneling microscopy study of InP(001) surface reconstruction* V. P. LaBella, Z. Ding, D. W. Bullock, C. Emery, and P. M. Thibado, J. Vac. Sci. Technol. A 18(4), 1492 (2000).

iv. Collaborators & Other Affiliations

1. G. Salamo, University Professor of Physics, Endowed Chair of Nanoscience, University of Arkansas, collaborated on research project entitled "Cross-sectional STM studies of nanostructures". (2005)
2. J. Robertson, Associate Professor of Astrophysics, Arkansas Tech University, Department Head, collaborated on research project entitled "Portable Spectrograph for Astronomical Observations". (2005)
3. L. Kondrick, Assistant Professor of Physical Science, Arkansas Tech University, collaborated on research project entitled, "Real-Time Classroom Assessment". (2005)
4. W. Gonzales-Espada, Assistant Professor of Physical Science, submitted a collaborated paper entitled "Speedeness and Classroom Response Systems: A Pilot Study", submitted to *The Physics Teacher.* (2004)
5. P. Buford, Assistant Professor of Electrical Engineering, collaborated on research project entitled "Portable Spectrograph for Astronomical Observations". (2005)
6. P. Thibado, Associate Professor of Physics, University of Arkansas, Post-doc Advisor; collaborated in preparation of 3 grants, 20 papers (3 appearing in *Physical Review Letters* and 1 in *Science*), 23 presentations, and two patents.

v. Presentations (Examples for last five years)

1. *Mock Automated Warehouse Autonomous Robot*, Anthoney Tusing, Adam Effrein, Daniel Bullock and Patricia Buford, Arkansas Tech University undergraduate Research Symposium Spring 06.
2. *Portable Spectrograph for Astronomical Observations*, Anthoney Tusing, Adam Effrein, Patricia Buford, Jeff Robertson, and Daniel Bullock, Arkansas Space Grant Consortium Research Symposium Spring 06.
3. *Cross-Sectional STM Studies*, Taylor Duncan and Daniel Bullock, Research Experience for Undergraduates research symposium Summer 05.
4. *Automated Growth Rate Calculations for Electronic Device Production*, Willie Nelson, Alvin Ong and Daniel Bullock, Arkansas Academy of Sciences Research Symposium Spring 05.
5. *Student Response Time in Introductory Level Physical Science Class*, Daniel Bullock and Wilson Gonzalez-Espada, Arkansas – Oklahoma – Kansas Spring 2004 meeting.

6. *Growth Rate Calculations for Electronic Device Production*, Willie Nelson, Alvin Ong and Daniel Bullock, Arkansas Tech Undergraduate Research Symposium Spring 04.
7. *Hyper Interactive Teaching Methods Using Remote Control Technology*, The 8th Hot Springs Educational Technology Institute Conference, June 13–14, 2001, Hot Springs, Arkansas.
8. *Electron Spin Scattering Across a p-type GaAs (110) Step Using a Ferromagnetic-Metal STM Tip*, The 85th Annual Meeting of the Arkansas Academy of Sciences, April 13–14, 2001, Conway, Arkansas.

vi. Honors and Awards (Grant Proposals- Examples for the last five years)

1. Awarded Faculty Research Grant entitled, "Growth and Characterization of Magnetic Nanoparticles", worth $2,000.
2. Awarded Nanoscience Education Initiative funding from Dr. Jack Hamm, Vice President of Academic Affairs worth $130,000.
3. Principal Investigator on an Arkansas Space Grant Consortium – NASA grant entitled, "Cross-Sectional STM sample Preparation Algorithms", worth $14,150.
4. Awarded summer research fellowship from the Materials Science and Engineering Center (MRSEC) at the University of Arkansas nanoscience labs, worth $13,000 for three months (2005).
5. Co-principal investigator on Arkansas Tech University Undergraduate research Council grant entitled, "Mock Automated Warehouse Autonomous Robot", worth $3,486 (2005).
6. Principal investigator on Arkansas Tech University Assessment Committee grant entitled, "Real-Time Classroom Assessment", worth $1,220 for one year. This project, in collaboration with another faculty member, studies the effects of different technologies used in the classroom on learning (2004).
7. Co-principal investigator on Arkansas Space Grant Consortium – NASA grant entitled, "Portable Spectrograph for Astronomical Observations", worth $4,415 for one year. This project in involves three faculty members from two different departments. Additionally, the funds from this project will support two undergraduate students to conduct the research for one year. These students were able to visit Johnson Space Center to review current NASA research projects.
8. Principal investigator on Arkansas Space Grant Consortium – NASA grant entitled, "Dynamic Electronic Device Production Software", worth $2,600 for one year. This proposal was able to fund research performed by two undergraduate students in 2004. Additionally, these students were able to travel to the Stennis Space Center to observe current NASA research projects.
9. Principal investigator on Arkansas Tech University Undergraduate Research grant entitled, "Growth Rate Calculations", worth $2,500 for one year. This proposal was able to fund research performed by two undergraduate students in 2003.
10. Participating investigator on National Science Foundation (NSF) Materials Research Instrumentation (MRI) program entitled, "Development of a Spin-Polarized Field Effect Transistor" worth $750,000 over 2 years.