RECEIVED

Final Report Grant No. DE-FG03-85ER45192

JUL 24 1997

Melting in Adsorbed Films

OSTI

DOE/ER/45192--T4

This grant ran from February 1, 1981 to January 31, 1995. It resulted in a rich output of experimental results that will have a lasting impact on the field of phase transitions in lower dimensions. It produced 33 formal publications and 7 Ph.D. theses. It has also opened the door for ongoing research, for which continued funding is being sought.

The scientific output of the project has been detailed in a series of progress reports that need not be summarized here. Instead I have appended to this report a list of all the publications and theses arising out of this grant, plus copies of those papers published in the last two years. The most recent paper, published in Physical Review Letters in January 1995, the last month of the grant, explains the remarkable phenomenon of reentrant layering in thin adsorbed films, and opens a dramatic new class of possible phases and phase transitions at crystal surfaces.

Perhaps the most important consequence of this grant is the fine group of scientists it produced. Here is a list of the 7 Ph.D.'s that were supported and their present positions:

Dr. Jeffrey M. Greif (1982) - Inference Corp (an advanced mathematical software firm)

Dr. Jeffrey J. Hamilton (1983) - Research staff, University of Maryland, College Park

Dr. Michael B. Weimer (1986) - Professor, Texas A&M University

Dr. Michael B. Pettersen (1988) - Assistant Professor, Oberlin College, Columbus, OH

Dr. Roya Maboudian (1988) - Assistant Professor, University of California, Berkeley

Dr. Mark J. Lysek (1991) - Member technical staff, Jet Propulsion Laboratory (Caltech)

Dr. Peter K. Day (1993) - Humboldt Postdoctoral Fellowship, Göttingen, Germany

I wish to thank the Department of Energy for the bountiful contribution this grant has made to science. The recent publications and the full list of publications supported by the grant are attached.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

Publications Supported by this Grant

1. Probing the Helium-Graphite Interaction, M.W. Cole, D. Frankl and D.L. Goodstein, *Rev. Mod. Phys.* **53**, 199 (1981).
2. Orientational Ordering in Incommensurate Solid Helium Monolayers on Graphite, J. Greif and D.L. Goodstein, *J. Low Temp. Phys.* **44**, 347 (1981).
3. Dislocations and Melting in Two Dimensions: The Critical Region, J. Greif, D.L. Goodstein and A. Silva-Moreira, *Phys. Rev. B* **25**, 6838 (1982).
4. Deviations from Two-dimensionality in Classical Adsorbed Films, P.A. Monson, M.W. Cole, F. Toigo, and W.A. Steele, *Surf. Sci.* **122**, 401 (1982).
5. The Coupling of Phonons to a Helium Atom Adsorbed on Graphite, R.D. Williams, M.W. Cole, and S.E. Koonin, *Phys. Rev. B* **28**, 1076 (1983).
6. The Shape of Physical Adsorption Potentials, G. Valali, M.W. Cole, and J.R. Klein, *Phys. Rev. B* **15**, 3064 (1983).
7. Helium Interactions as a Probe of the (111) Surface of Diamond, G. Vidali, M.W. Cole, W.H. Weinberg, and W.A. Steele, *Phys. Rev. Lett.* **51**, 118 (1983).
8. Thermodynamic Study of Methane Multilayers Adsorbed on Graphite, J.J. Hamilton and D.L. Goodstein, *Phys. Rev. B* **28**, 3838 (1983).
9. Quadrupole Contribution to the Physisorption Interaction, Xue-Pei Jiang, F. Toigo, and M.W. Cole, *Chem. Phys. Lett.* **101**, 159 (1983).
10. Is there a Universal Potential of Physical Adsorption?, G. Vidali, M.W. Cole, S. Rauber, and J.R. Klein, *Chem. Phys. Lett.* **95**, 213 (1983).
11. Phase Diagrams of Multilayer Adsorbed Methane, D.L. Goodstein, J.J. Hamilton, M.J. Lysek and G. Vidali, *Surf. Sci.* **148**, 187 (1984).
12. Two-dimensional Critical Points and Critical Isotherms, J.J. Hamilton, *Phys. Rev. B* **32**, 4760 (1985).
13. Observation of a First-Order Triple-Point Dewetting Transition in Methane Adsorbed on Graphite, M.J. Lysek, M.S. Pettersen and D.L. Goodstein, *Phys. Lett.* **115A**, 340 (1986).
14. The Multilayer Melting Transition in Methane Adsorbed on Graphite, M.S. Pettersen,

M.J. Lysek and D.L. Goodstein, *Surf. Sci.* **175**, 141 (1986).

15. Triple-Point Dewetting and Wetting of Methane Adsorbed on Graphite, M.J. Lysek, M.S. Pettersen and D.L. Goodstein, *Bull. Am. Phys. Soc.* **32**, 433 (1987).
16. Near Equilibrium Desorption of Helium Films, M. Weimer, R.M. Housley and D.L. Goodstein, *Phys. Rev. B* **6**, 5199 (1987).
17. Observation of Near-Surface Damage by Phonon Scattering, R. Maboudian, C. Carraro, D.L. Goodstein, R. Housley, and T. Tombrello, *Phys. Rev. B* **38**, 12190 (1988).
18. Reflection of Phonons from Radiation Damaged Regions, Poster Session, 1988 March Meeting of the American Physical Society, New Orleans, Louisiana, March 21-25, 1988.
19. Invited talk, Wetting and Melting in the Methane/Graphite, M.S. Pettersen, M.J. Lysek and D.L. Goodstein, the 62nd Colloid and Surface Science Symposium, The Pennsylvania State University, University Park, PA, June 19-22, 1988.
20. NMR Study of Thick Films of Methane on Graphite, M.S. Pettersen and D.L. Goodstein, *Surface Science* **209**, 455 (1989).
21. Wetting and Melting in the Methane/Graphite, M.S. Pettersen, M.J. Lysek and D.L. Goodstein, *Langmuir* **5**, 563-566, 1989.
22. Melting in Multilayer Adsorbed Films, M.S. Pettersen, M.J. Lysek and D.L. Goodstein, *Phys. Rev. B* **40**, 4938 (1989).
23. Invited talk, Phase Transitions in Multilayer Adsorbed Films, D. Goodstein. *Surface Physics in Material Science Seminar*, El Paso, 1990. Published in MRCE Monographs Series on Materials and Processes.
24. Invited talk, The Methane/Graphite Phase Diagram, D.L. Goodstein, M.A. LaMadrid, M.J. Lysek, in *Proceedings of the NATO Advanced Study Institute and International Course on Phase Transitions in Surface Films 2*, ed., H. Taub, G. Torzo, H.J. Lauter and S.C. Fain, Jr. (Plenum Press, New York, 1991) p. 437.
25. Lysek, La Madrid, Day and Goodstein, "Adsorption hysteresis, capillary condensation and melting in multilayer methane films on graphite foam," *Langmuir* **8**, 898-900, 1992.
26. Invited talk, Phases and Phase Transitions in the First Few Layers of Methane, Argon and Krypton Adsorbed on Graphite, D.G. Goodstein, P.K. Day, M. LaMadrid, M.J. Lysek, *Materials Research Society, Fall Meeting 1992*, held in Boston, MA,

Mat. Res. Soc. Symp. Proc. Vol. 280, 319 (1993)

27. The Melting of Unsaturated Capillary Condensate, M.J. Lysek, M. La Madrid, P.K. Day and D.L. Goodstein, *Langmuir* **9**, 1040-1045, 1993.
28. Phase Transitions in Argon Films, P.K. Day, M.J. Lysek, M. La Madrid and D.L. Goodstein, *Phys. Rev. B* **47**, 10716 (1993).
29. A Fully Automated Scanning Ratio Calorimetry for Use in Adsorption Studies, M.J. Lysek, P.K. Day, M. LaMadrid and D.L. Goodstein, *Rev. Sci. Instrum.* **63**, 5750-5759, 1992.
30. Heat capacity of multilayer methane on graphite: Phase transitions in the first four layers, M.J. Lysek, M. LaMadrid, P.K. Day and D.L. Goodstein, *Phys. Rev. B* **47**, 7489 (1993).
31. Multilayer krypton phase diagram, P.K. Day, M. LaMadrid, M.J. Lysek and D.L. Goodstein, *Phys. Rev. B* **47**, 7501 (1993).
32. Evidence for a preroughening transition and a disordered flat phase in solid argon and krypton," LTXX International Conference on Low Temperature Physics Eugene Oregon, August 4-11, 1993.
33. Preroughening and Reentrant Layering Transitions in Triangular Lattice Substrates, P.B. Weichman, P.K. Day and D.L. Goodstein, *Phys. Rev. Letters* **74**, 418 (1995).

Theses Supported by this Grant

1. Do Helium Monolayer Films Melt by Unbinding of Dislocations?, Jeffrey M. Greif, Ph.D. Thesis, California Institute of Technology, 1982.
2. A Thermodynamic Study of Methane Multilayers Adsorbed on Graphite, Jeffrey J. Hamilton, Ph.D. Thesis, California Institute of Technology, 1983.
3. Thermal Desorption of Helium Films: Theory and Experiment, Michael B. Weimer, Ph.D. Thesis, California Institute of Technology, 1986.
4. Melting of Methane Adsorbed on Graphite Studied by Nuclear Magnetic Resonance, Michael Pettersen, Ph.D. Thesis, California Institute of Technology, 1988.
5. In Situ Observation of surface and Near-Surface Modification Using Scattering of Ballistic Phonons, Roya Maboudian, Ph.D. Thesis, California Institute of Technology,

1988.

6. A Thermodynamic Study of Layering and Capillary Condensation of Methane Adsorbed on Graphite Foam, Mark J. Lysek, Ph.D. Thesis, California Institute of Technology, 1991.
7. On the Transition from Two- to Three-Dimensional Behavior in Adsorbed Films, Peter K. Day, Ph.D. Thesis, California Institute of Technology, 1993.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.