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# "Nonequilibrium Phase Transitions" Final Report

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**04-ERD-108 “Nonequilibrium Phase Transitions”**  
**Final Report**  
Andrew Ng, Physical Sciences Directorate

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Summary

The goal of the project is to understand the behavior and properties of solid-plasma transition in the uncharted, nonequilibrium high energy density regime. The work completed is documented in three publications:

- (1) “*Optical Properties in Nonequilibrium Phase Transitions*”, T. Ao *et al.*, Physical Review Letters 96, 055001 (2006) [UCRL-JRNL-218075],
- (2) “*Broadband dielectric Function of Nonequilibrium Warm Dense Gold*”, Y. Ping *et al.*, Physical Review Letters 96, 255003 (2006) [UCRL-JRNL-221126], and
- (3) “*Dielectric Function of Warm Dense Gold*”, Y. Ping *et al.*, accepted for publication in Physics of Plasmas on January 23, 2008 [APS DPP Invited paper, UCRL-CONF-237017]

Paper #1 presents the first known measurement of the critical lattice energy density needed for disassembly of the lattice in solid-plasma transition under nonequilibrium, high energy density conditions. This is a fundamental parameter and a well-defined benchmark for testing new theories describing such phase transition.

Paper #2 describes the discovery of bandstructure effects in a quasi-steady-state prior to the onset of plasma transition in gold under ultrafast laser excitation. This is the first evidence of a super-heated solid phase that can exist at high energy density under highly nonequilibrium conditions. The finding becomes a key stimulus, driving advance in non-equilibrium finite-temperature condensed matter theory.

Paper #3 expands on the discussion presented in Paper #2, adding important experimental details and results of new *ab initio* calculations. The latter suggests the need to examine non-equilibrium electron distribution and possibly non-adiabatic effects.

In addition to journal publications, many invited talks have been given at leading national and international scientific meetings, including:

- (1) International Workshop on Warm Dense Matter, Vancouver, Canada, October 6-8, 2005: “*Measurements of single-state electrical conductivities of warm dense gold*”, A. Ng [UCRL-ABS-215918]
- (2) 29<sup>th</sup> European Conference on Laser Interaction with Matter (ECLIM), Madrid, Spain, June 12-16, 2006: “*Broadband dielectric function of non-equilibrium warm dense gold*”, A. Ng [UCRL-PRES-221835]

- (3) International Workshop on Warm Dense Matter, Porquerrolles, France, June 13-16, 2007: “*Isochoric Laser Heating for Warm Dense Matter Studies*”, A. Ng [UCRL-CONF-231298]
- (4) [Super-Plenary](#), IEEE Pulsed Power & Plasma Science Conference, Albuquerque, NM, June 18-21, 2007: “*Warm Dense Matter – an emerging frontier in plasma & condensed matter science*”, A. Ng [UCRL-PRES-231624]
- (5) Workshop on Foundation and Application of Density Functional Theory, Kashiwa, Japan, August 2007: “*First-principles studies of material under extreme conditions*”, T. Ogitsu [UCRL-PRES-233129]
- (6) Inertial Fusion Science & Applications (IFSA) Conference, Kobe, Japan, September 9-14, 2007: “*Broadband Dielectric Function of Non-Equilibrium Warm Dense Gold*”, A. Ng [UCRL-PRES-234450]
- (7) Directed Energy Symposium, Huntsville, AL, November 5-8, 2007: “*Dielectric Function, Electron-Phonon Coupling & Pressure Ionization in the Warm Dense Matter Regime*”, A. Ng [UCRL-PRES-236076]
- (8) APS Division of Plasma Physics Annual Meeting, Orlando, FL: “*Broadband Dielectric Function of Nonequilibrium Warm Dense Gold*”, Y. Ping [UCRL-PRES-236302]

The project has also provided research training for students including:

- (1) Tommy Ao - Ph.D. student; now Staff Physicist at Sandia National Laboratories, Albuquerque, NM
- (2) Edward Lee – Undergraduate Co-Op student; now graduate student at MIT
- (3) Heywood Tam - Undergraduate Co-Op student; now graduate student at Caltech
- (4) Ingrid Koslow - Undergraduate Co-Op student; now graduate student at UC Santa Barbara
- (5) Duncan Hanson - Undergraduate Co-Op student; now graduate student at Cambridge University