

# *New Directions in Mineral Physics: Multidisciplinary High Pressure Science*

**Russell Hemley and Ho-kwang Mao**

**2005 Balzan Prize for Mineral Physics**

**Balzan GPC Adviser:** Enric Banda

**Researchers:** Pierre Beck, Lin Wang, Charles Qiaoshi Zeng, Claire Barkett, Daniel Cohen, Maura James (postdoctoral fellows and doctoral students); Andrew Kung, Alexander Levedahl, Manchali Madurri, Jaqueline Rivera, Ari Benjamin, Kevin Hernandez, Tao Liu, Louis Loubeyre, Juliana Mesa, Viktor Rozsa, Brandon Wilfong, Keenan Brownsberger, Anne Davis, Reed Mershon (high school students)

**Affiliated Institution:** Carnegie Institution of Washington, Geophysical Laboratory

**Period:** 2006-2016

Russell Hemley is Research Professor at George Washington University and Director of the Carnegie/DOE Alliance Center.

With the second half of their Balzan Prize, Hemley and Mao implemented a project focused on bringing bright young people from diverse backgrounds into the multidisciplinary field of High Pressure Science. Research in this new field is expected to bring about breakthroughs in applications to mineralogy, geophysics, geochemistry and bioscience, as well as specific areas such as hydrogen storage, superhard materials and superconductivity. The project was focused on training and its goal was the exploration of the new high-pressure dimension in multidisciplinary physical sciences. The fellowships encouraged the development, design, and fabrication of new instrumentation that exploited the CVD diamond technology developed by Professors Hemley and Mao. Publications and dissemination of results have also been financed.

The following post-doctoral fellows and doctoral students received Balzan support: Pierre Beck (Balzan Prize postdoctoral associate from 2006-2007): development of time-resolved (i.e., dynamic) high pressure-temperature phenomena with diamond anvil cells; Lin Wang (Balzan Prize postdoctoral associate): development of a new method for the synthesis of controlled shape C60 fullerene nanorods, development of

a new technique to integrate the high-pressure diamond anvil cell with the high brilliance x-ray beam focused down to 50-200 nm size at the Advanced Photon Source, and work at the High Pressure Synergetic Consortium (HPSynC) at the Advanced Photon Source (APS), Argonne National Laboratory (ANL) in 2008; Charles Qiaoshi Zeng (Balzan Prize support, 2008): x-ray diffraction experiments at the APS synchrotron facility and discovery of a new type of alloy and a new phenomenon in metallic glass that have far-reaching impact in fundamental physics as well as materials applications.

The following high school students also received Balzan Award support: Andrew Kung: to develop a high-pressure project studying the pressure, temperature and temporal effects on a newly discovered  $O_2$ - $H_2$  alloy; Daniel Cohen: to study novel electronic phenomena in diamond, in particular, to produce a new material with metallic electrical conductivity, and possibly superconductivity; Alexander Levedahl: to investigate the high pressure-temperature behavior of hydrogen-containing ice materials known as hydrogen clathrates; Claire Barkett: follow-up on the earlier work of Jaqueline Rivera by synthesizing several solid solutions in the  $Fe_2O_3$ - $Al_2O_3$  system very close to the 1:1  $FeAlO_3$  composition; Maura James: to investigate high pressure clathrate formation in the  $H_2O$ - $NH_2$ - $H_2$  ternary system with Stephen Gramsch and Maddury Somayazulu in an exploratory project to work out special techniques for sample loading and mapping the composition of the mixture inside the diamond anvil cell; Manchali Madurri: a study of  $H_2$ -crown ether complexes at high pressure that led to his being named a semifinalist in both the Intel and Siemens national science fair competitions; Jaqueline Rivera: development of a new room-temperature, solution-based synthesis method for solid solutions in the  $Fe_2O_3$ - $Al_2O_3$  solid solution system; Ari Benjamin: equation of state of the fluorinated copolymer Kel-F 800 to near megabar pressures; Kevin Hernandez: Raman spectroscopy studies of carbon dioxide-water system at high pressure; Tao Liu: optical emission spectroscopy studies of MPCVD diamond growth; Louis Loubeyre: heterogeneity in the dynamics of methanol under high pressure; Juliana Mesa: geochemistry of Fe stable isotopes – from planets to minerals; Maimon Rose: investigating the electrocaloric piezoelectric effects in  $LiNbO_3$  and PMN-PT using MD simulations; Viktor Rozsa: pressure studies of hydrogen-loaded hydroquinone clathrate; Nichole Valdez: high pressure synthesis of  $Fe_2SiO_5$ ; Kevin Hernandez (second internship): reactivity at high pressure and temperature; Olivia Reyes-Becerra: synthesis of single-crystal  $Na_4Si_{24}$  clathrate; Brandon Wilfong: in-situ Raman spectroscopic investigation of relaxor multiferroic  $Pb(Fe_{0.5}Nb_{0.5})O_3$  under high pressure and temperature conditions; Keenan Brownsberger: synthesis of palladium hydrides at

extreme conditions; Anne Davis: phase transitions in silicon quantum dots for solar energy conversion; Reed Mershon: the role of oxygen fugacity in elemental fractionation between basaltic and sulfidic liquids.

Although the funds for the Balzan project have been spent, the student training activities that were initiated through the project continue in Chicago.

## Publications

The most recent publications are listed below. For a complete list of publications, see <https://www.balzan.org/en/prizewinners/russell-j--hemley-and-ho-kwang-mao/research-project-russell-mao> and previous editions of the *Overview*.

- Beck, P., Goncharov, A.F., Montoya, J.A., Struzhkin, V.V., Militzer, B., Hemley, R.J., Mao, H.K. 2009. Response to “Comment on ‘Measurements of the thermal diffusivities at high-pressure using a transient heating technique’.” *Applied Physical Letters*. Volume 95, Issue 9.
- Goncharov, A.F., Beck, P., Struzhkin, V.V., Haugen, B.D., Jacobsen, S.D. 2009. Thermal conductivity of lower mantle minerals. *Phys. Earth Planet. Inter.* 174: 2432.
- Liang, Q., Chin, C.Y., Lai, J., Yan, C.S., Meng, Y.F., Mao, H.K., Hemley, R.J. 2009. Enhanced growth of high quality single crystal diamond by MPCVD at high gas pressures. *Appl. Phys. Lett.* 94: 024103.
- Liang, Q., Yan, C.S., Meng, Y., Lai, J., Krasnicki, S., Mao, H.K., Hemley, R.J. 2009. Recent advances in high-growth rate single-crystal CVD diamond. *Diamond and Related Materials*. Volume 18: 698-703.
- Liang, Q.C., Yan, S., Meng, Y.F., Lai, J., Krasnicki, S., Mao, H.K., Hemley, R.J. 2009. Enhancing the mechanical properties of CVD single-crystal diamond. *Journal of Physics: Condensed Matter*. Issue 36.
- Sun, L., Yi, W., Wang, L., Shu, J., Sinogeikin, S., Meng, Y., Shen, G., Bai, L., Li, Y., Mao, H.K., Mao, W.L. 2009. X-ray diffraction studies and equation of state of methane at 200 GPa. *Chem. Phys. Lett.* 473: 72-74.
- Wang, L., Pan, Y., Ding, Y., Yang, W., Mao, W.L., Sinogeikin, S.V., Meng, Y., Shen, G., Mao, H.K. 2009. High-pressure induced phase transitions of  $Y_2O_3$  and  $Y_2O_3:Eu^{3+}$ . *Appl. Phys. Lett.* 94: 061921.
- Wang, L., Ding, Y., Yang, W., Mao, W.L., Liu, W., Cai, Z., Shu, J., Shen, G., Mao, H.K. 2009. Application of nano/submicron-focused x-ray probe for ultrahigh-pressure studies. *High Pressure Synchrotron Science Workshop (Argonne IL, 6-8 May 2009)*.