**COMPRES Multi-Anvil Support Facility**

2016 COMPRES Annual Report

November 2015 – October 2016

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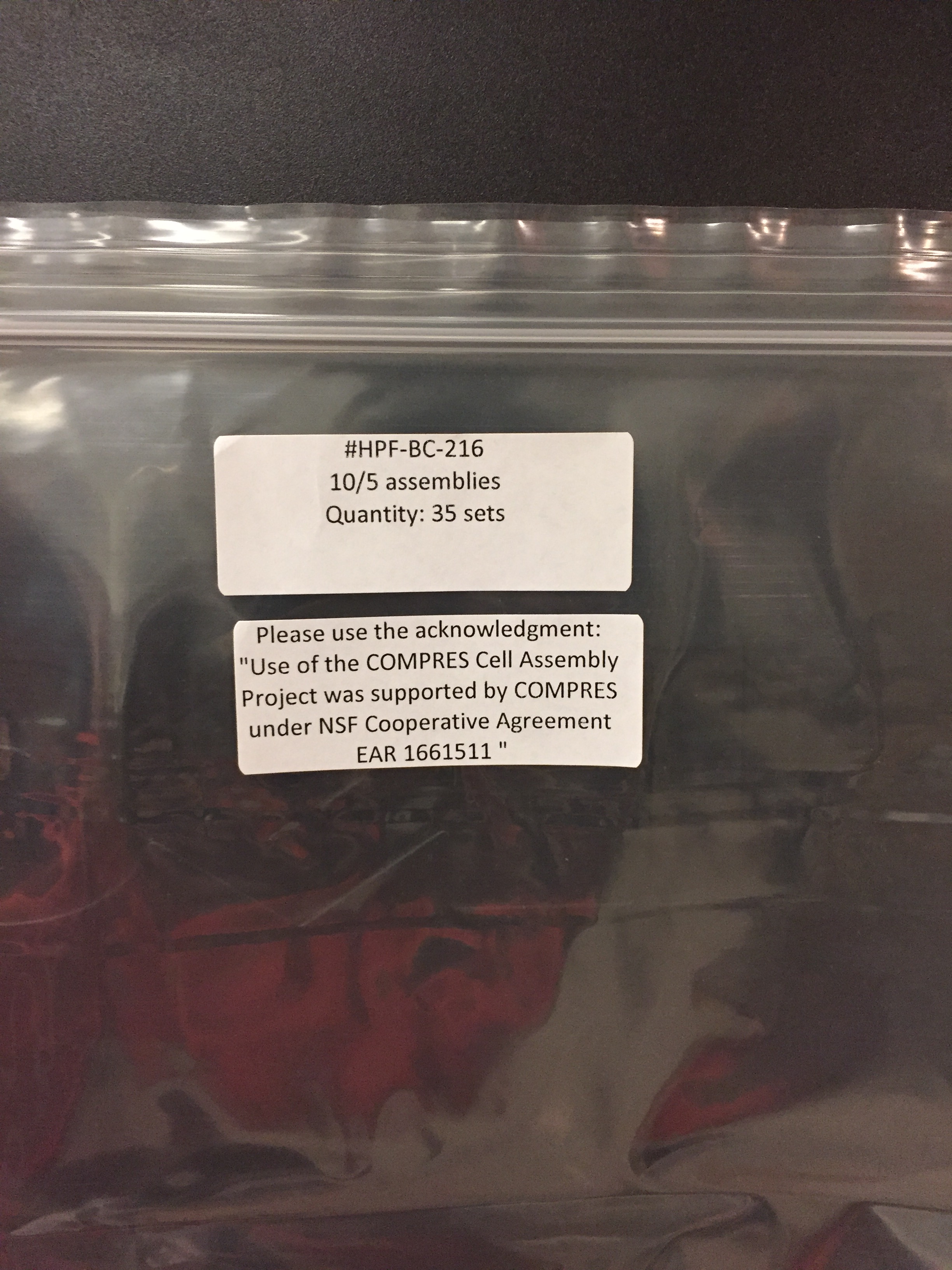
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**Overview**

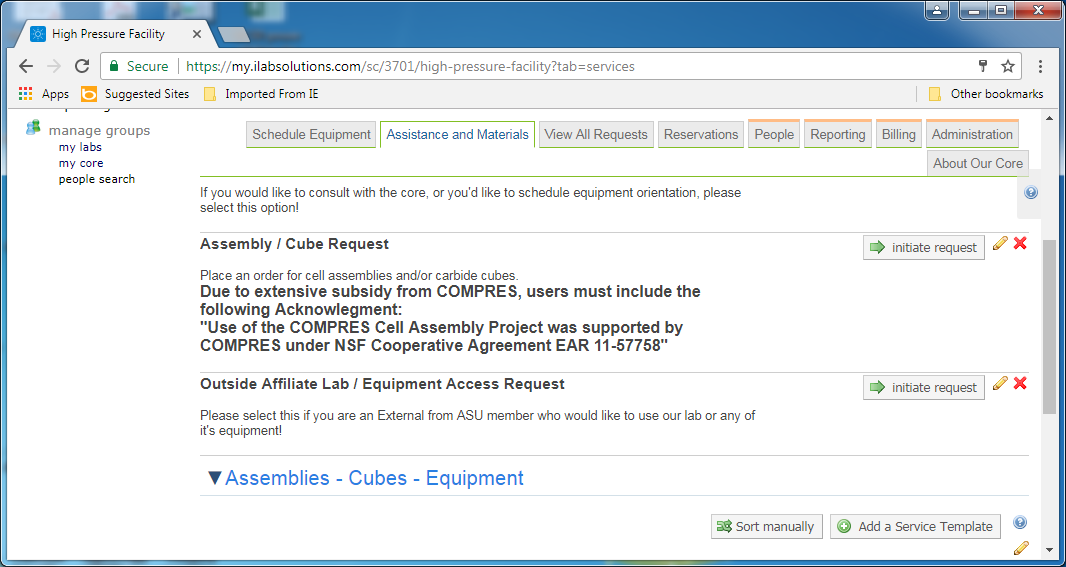
*Summarizing the facility, its capabilities, operations, achievements, etc.*

The COMPRES Multi-Anvil Cell Assembly/Support Facility, currently located in the High Pressure Multi-Anvil Laboratory at Arizona State University, is a Facility where multi-anvil cell assemblies and methods are developed and distributed to participating laboratories around the World. The availability of standardized, well-tested and carefully calibrated assemblies, along with brand-new assemblies that are co-designed with outside laboratories based on needs for new capabilities, have enabled a growing body of research in the field of high pressure. Open discussion of techniques and results helps to disseminate this helpful information among high pressure laboratories. Laboratories with new multi-anvil equipment that might have had difficulty achieving state of the art pressures and temperatures if left on their own to develop their assemblies, have been able to participate in research and reach their desired pressure-temperature conditions more easily, and to benefit from a body of openly shared knowledge about multi-anvil techniques. We have assisted both conventional laboratories and *in-situ* facilities specializing in large-volume high-pressure experiments. In addition, we are also developing, testing and distributing various tungsten carbide and other super-hard anvils for multi-anvil research.

In terms of funding, this project consists of two major components. In the first component, new developments are funded using the budget from COMPRES. Ideas for new assemblies and methods are submitted by interested people, and prototypes of parts and/or entire assemblies are produced for testing. Once an assembly or method is well documented and is proven to be largely capable of doing what it claims, it can be moved into a production mode where it becomes part of an ASU-based Cost of Sales program where people simply purchase the assemblies for their use. In doing this, the methods and techniques remain open in case some laboratories want to do their own fabrication (which they have in some cases). The COMPRES project co-exists with the Cost of Sales program and provides a kind of insurance in case something in the Cost of Sales program goes wrong, and for that reason we consider the Cost of Sales program dependent on the COMPRES project. Our experience indicates that (so far) the Cost of Sales program needs the COMPRES program to be successful. For that reason, we ask users of that program to acknowledge COMPRES in their efforts (cf. Figure 1).



*Figure 1A: Part of a typical line item in a COMPRES cell assembly order showing the acknowledgment request on the package of parts.*

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*Figure 1B. Screen shot of a similar acknowledgment request in iLab that users see before they order the assemblies.*

**Scientific Highlights**

*Brief discussion of a small number of featured studies illustrating recent successes from the beamline for this year. Encourage users to send in one-pagers to include in the appendices of your annual report.*

The benefits of the project to the US and world high-pressure communities are immediate and tangible, we believe. Many papers are being published that have benefitted from the freely available materials and methods that we have provided. A running list of publications is being maintained by our effort and the current rate of traceable publications is about twenty per year. For our one-pagers this year, we have selected three major successful users of our project to highlight their own research, representing each of the three main types of users that we have. The first is the conventional, working laboratory using our standard assemblies, and for this we have selected Dan Shim’s efforts at ASU (including Leinenweber as a collaborator). The second is the United States beam-line efforts, and though we have several, we have selected GSECARS with Yanbin Wang and Tony Yu because of a consistent and very active relationship. The third is foreign laboratories, and because China has had a significant share of the foreign orders in recent years, and because one particular laboratory has had recent high-profile results using our assemblies, we have chosen the Luo laboratory at Yanshan University in China to provide a sample one-pager from a foreign laboratory. Those three one-pagers are attached to this document.

**Beamline Personnel**

*Discuss management structure; current beamline staff; other key personnel, and sources of funding, including funding external to COMPRES (this is important to identify how the facility personnel leverage COMPRES support). Any changes in COMPRES-supported staff should be discussed, with CVs of new hires included as appendices.*

We have three personnel (all undergraduates) that have sometimes been on other projects as well but are also on-and-off supported on the COMPRES project depending on funding and workload. Dzmitry Kisealu and Logan Leinbach are both very early-career undergrads (currently Sophomores) who have become very expert at providing the materials and supplies for the COMPRES end users. They are familiar with almost every aspect of each COMPRES official assembly and have been packing and distributing assembly orders to many end-users. It can be confidently stated that without the help of assistants, this whole project would be untenable! An attempt by one of the PI’s to work without assistants in the winter of 2015-2016 provided definitive proof of this and led to the hiring of these two undergraduates.

Devin Keating is a highly skilled upperclassmen who can help us physically upgrade the whole laboratory in a way that will benefit COMPRES because this is where many of our assemblies are first tested. He has just joined the staff a few weeks ago. He will also be moved from COMPRES to other sponsored projects depending on the nature of the work needed.

Some assistance is obtained from funding outside COMPRES. Significant improvements in our datalogging and automation control have been provided recently with help from Douglas Daniel, an ASU employee who has been able to assist part-time in our automation efforts (not paid by COMPRES). The ability to track run variables while testing COMPRES assemblies is very important in troubleshooting the assemblies before they are too widely released to the general public. Two other ASU employees, Grant Baumgartner and David Wright, helped to set up the new furnace that UNM has purchased for preparing high-pressure standards.

Kurt Leinenweber is requesting 1 month of his salary (on a 12-month basis) to defray the costs to the State of Arizona for work done for COMPRES.

**Beamline Operations**

*Describe beamline operations in the past year. Include the amount of beamtime available; the relationship between COMPRES and the synchrotron facility regarding beamline operations; beamtime proposals and other beamline access; and other relevant discussion.*

*COMPRES requires also the following specific statistics for the past two years for each beamline:*

*Number of beamtime proposals received* 71 orders in iLab, including 43 orders for assemblies totaling 1712 assemblies; the rest were carbide and assorted ceramic parts. Total revenue was $245,640.

*Number of beamtime proposals granted beamtime* All requestors were provided with cell assemblies and materials.

*Total number of shifts requested* 71 orders in iLab.

*Total number of shifts granted* All 71 orders

*Total number of shifts available* We haven’t reached the limit of possible available assemblies though we are pushing the limit at times.

*Oversubscription rate (= shifts requested / shifts available)* 1.0 We hope to not have to turn down orders for assemblies, and we do not assess the merits of each program when we provide the assemblies. In that sense we are quite different from a beamline where proposals are reviewed for merit.

*Number of visits by distinct research groups* N/A since it’s a mail-in service.

*Number of unique users, categorized by affiliation (University, Gov’t Lab/agency, Private institution, or Industry) and by origin (USA, Canada, Europe, Asia, Other)* Please see Table showing a list of COMPRES users.

*Total number of person-visits* 71 unique records in iLab

*Number of undergraduate users*

*Number of graduate student users*

*Number of visits funded by each funding agency (NSF, DOD, DOE, Foreign/Other)*

*Please be clear about how shifts are counted, especially with regard to side stations and parasitic modes of operation. Details of the successful proposals, beamtime allocated, and total usage should be provided in an appendix.*

**Performance Metrics**

*This information has been requested by the NSF-IF program managers and is part of the reporting requirements written into our 5-year Cooperative Agreement with the NSF. As such, you are requested to supply this information on an annual basis. To make reporting easier and to obtain uniformity in the information we receive, two files are attached to be used as templates for the Performance Metrics reporting.*

*One spreadsheet is for user statistics for the past year. We require: PI name, country, funding source, and beamtime allocation. Please also provide:*

*General User Time for COMPRES: For higher-ranked proposals with beamtime allocated by the facility.*

*Contributing User Time: Allocated for COMPRES users who were not assigned GU time.*

*Total time for COMPRES users (there will usually be GU and CU COMPRES users).*

*The second template is for the upcoming run cycle (that is, beyond the current run cycle). These tables are hopefully self-explanatory. If there are any questions, please let me know.*

**Beamline Community Activities**

*Any outreach activities, workshops hosted, media features highlighting beamline activity, safety improvements, etc. should be summarized. Other activities of the beamline scientists, for example related to their professional development, independent research, or other community activity, could be discussed here too.*

**Beamline Development**

*COMPRES beamlines are typically in a state of continuous development. Discuss recent improvements, ongoing upgrades, and important problems or challenges to the facility.*

In order to provide the best testing of the performance of our cell assemblies and carbide, we are working on improvements to our automation and datalogging. This has been made possible by the efforts of an ASU employee (not paid by COMPRES), Douglas Daniel, who has been working part-time since July 2017 to create a new pressure control and datalogging platform for our presses in LabView. The system currently has pressure control and datalogging of oil pressure and sample temperature. The next step will be to datalog voltage and amperage of the power supply. This is being done at no cost to COMPRES, but will benefit COMPRES in terms of allowing a finer performance test of the assemblies and to ferret out subtle performance issues with the assemblies. A new undergraduate assistance with significant experience in “nuts and bolts” technical issues has also recently been hired (Devin Keating) to help with this effort on a day-to-day basis. This new hire has had noticeable effects in improving the user interface for the presses, which has an important impact on COMPRES assembly testing.

Our carbide project has two parts to it. One is the supplying of ready-to-use carbide anvils for users from the Cost of Sales program, including users that want very small numbers of anvils at the normal high-volume cost that are not be available from a company. The other is the testing of new grades or formulas of carbide. In the past year, we have switched over from truncating the anvils at ASU, to directly supplying anvils that are truncated at the factory. In the case of Toshiba Tungaloy carbide we are now providing 3 mm, 5 mm, and 8 mm-truncated anvils, truncated by Toshiba Tungaloy, in arbitrarily small (or large) batches to COMPRES users at a flat per-cube cost. In our own experiments we are quite happy to discover that the survival of these anvils is noticeably better than before, because the finish is very good and that finish results in fewer microcracks, where failures start. Those well-performing anvils are supplied directly to COMPRES users. This is done entirely through the Cost of Sales program at no cost to COMPRES. Meanwhile, we have purchased small test batches of Sandvik 6UF carbide with the COMPRES funding, with truncations of 5 mm, 8 mm and 12 mm, and those have also been testing very well. We have been testing them at ASU and a 12 mm batch is being tested by Alwin James at Stony Brook. His report is, “so far, so good.” Like the Tungaloy grinding, the grinding at Sandvik is extremely good, we cannot compete with it in our shop. Sandvik has told me personally that they use the same grinding procedures for the carbide Belt-type anvils in their high pressure fabrication facilities in Ohio (formerly the GE facilities) and that the grinding method is designed to remove microcracks – but at the same time the finish is purposely kept slightly rough to prevent slippage of gaskets. This knowledge is being transferred to the COMPRES community by supplying the anvils made by Sandvik for certain truncation ranges (especially the larger truncations that more closely resemble the conditions in the Belt apparatus).

On the more exotic carbide development side, we have purchased 24 micrograin and binder-free carbide anvils from Hamasho with 3 mm truncations (also including chamfers), which we will test in our lab and in the DELVE initiative. Those take many months to fabricate and so we are still waiting to receive those anvils. Hamasho advises that the anvils are shipping as of 11/14/17.

We always have a constant tug-of-war between starting material preparation, high pressure experiment, and analysis. Since we are located at a conventional University, there is an even higher expectation of help with the other aspects of the work – since obviously we are not as busy as a “beam-time” based establishment. This even though we do supply parts and designs for actual, live beam times! We have several offline requests a month or week for things like supplies of starting materials for calibrations, or powder x-ray diffraction on products. It would not reflect well on the COMPRES effort if we did not provide some help on these issues, so we do try to help to the best of our abilities. This year we have provided (in addition to assemblies and parts that are already documented) several x-ray diffraction patterns and optical observations of multi-anvil run products, free of charge.

**Planned Activities**

*Describe beamline improvements or other activities that are planned. For COMPRES facilities now moving their operations to a new beamline (at NSLS-II and/or APS), this should obviously include a detailed discussion of the transition plan, including a timeline of activities related to the move, and a description of how and where COMPRES-supported staff will be utilized during and after the transition.*

The plan for next year in terms of COMPRES research is the following:

**Forsterite ceramic thermal insulation.** We plan that this year will be the “year of forsterite.” We have just obtained (Nov 2017), for the first time, excellent samples of extruded porous/crushable forsterite ceramic from a very good Ceramics vendor. Forsterite has excellent thermal insulation properties (similar to zirconia) but is also fairly transparent to x-rays. Thus it has great promise as a thermal insulation material for *in-situ* assemblies. However, there is no reason not to use it *ex-situ* as well. Extrusion is the most inexpensive and least wasteful way to make ceramic pieces. We have not had great success in extruding zirconia up until now, and have continued to use the blocks from Japan combined with ultrasonic drilling, but forsterite extrusions are of good quality. Replacing zirconia with forsterite (especially for work below 14 GPa) could result in much cheaper assemblies. Furthermore, a dual in-situ, ex-situ assembly would achieve a longstanding goal of ours: to have a “hybrid” assembly where the knowledge of assembly performance obtained from in-situ measurements could be used in conventional laboratories to obtain a much better understanding of what is happening in our experiments.

We have been using a forsterite sleeve in one of our in-situ assemblies for years, but we did not develop this for ex-situ and other assemblies because it is not crushable – it is hard and has a glaze on the surface. Crushable ceramic, like the new formula, is more appropriate for high pressure assemblies because then the whole assembly deforms in a uniform manner.

Forsterite will also be tested as a DIA pressure medium. Matthew Whitaker is enthusiastic about this possibility and willing to test the material.

We are even planning to try the forsterite as a replacement for pyrex in piston-cylinder assemblies. It could eliminate problems caused by the high-temperature softening of pyrex.

**Larger assemblies**: The 18 mm octahedron assembly needs to be “symmetrized” in order to improve thermal gradients. This will require making new molybdenum leads and new grooved zirconia caps. No other modifications will be necessary (assuming that the new design has better thermal profiles as expected).

The 25 mm assembly, currently our largest and rarely used, has begun to attract demand. But there is a problem with this and basically all large assemblies: cost. The cost of machining a few zirconia sleeves from a $1000 block is prohibitive. We have developed a mullite octahedron for alternative thermal insulation, but mullite breaks down at only 6 GPa. We are optimistic that our new forsterite ceramic will turn out to be suitable for large assemblies that are used at high pressure. That includes the use of the large assemblies on superlarge presses, such as the 5000 ton press at Bayreuth, the 6000 ton press at Ehime, and the possible future 5000 ton press that is under discussion for installation in the United States.

**Carbide**: There is a Sandvik grade called 3UF. Our project was instrumental in starting the Sandvik 6UF trials that are occurring in the US this year. This has resulted in the discovery of a very good grade of carbide, and excellent price and finish grinding as well, that will benefit our community. However, the original interest from Ivan Getting in the 1990’s was in 3UF grade, a more brittle but also harder grade that might achieve higher pressures than were previously possible even with Toshiba Tungaloy Grade F. The current version of this is to see if 3UF can contribute to the DELVE effort to reach 50 GPa in a sustainable fashion. The DELVE effort is relying (so far) on only one grade of carbide, the Fujilloy Grade TJS01. It is known to have a high breakage rate, though reaching impressive pressures. Ultimately we want to find a carbide that can extend the pressure capabilities, but not break so much. We will test the pressure capabilities and survival rates of the Sandvik 3UF carbide this year, through the COMPRES project and will connect it to the DELVE initiative by using in-situ xrd if the preliminary tests at ASU go well.

**Budget**

The 5-year budget (2017-2022) for this facility is $557K as shown in the attached Excel file. The budget for the current request (2017-2018) is $110,341 as shown in the same file. The main difference between last year’s budget and this year’s is to reduce the salary request for K. Leinenweber from 1 month to 0.5 month, and to add undergraduate labor. Undergraduates were heavily used in the project in earlier years, then there was a period where KL did everything, and a year ago we went back to using undergraduates as much as possible as the demand kept increasing. The current undergraduates (Dzmitry Kisaleu, Logan Leinbach, and Devin Keating) are essential to the COMPRES project because they manage the stocks of assembly parts (though the stocks are still ordered 100% by Kurt Leinenweber because of technical complexity) and do all the packaging and shipping, plus do a lot of cell assembly preparation for testing.

**Appendices**

Table 1: List of COMPRES cell assemblies and the number provided in a 12-month period (Nov. 1, 2016-Nov. 1, 2017).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Size and Name** | **Type of heater** | **Max Pressure** | **Max Temperature** | **Number provided Nov 2016-Nov 2017** |
| *Standard 6-8 (Kawai type) assemblies* | | | | |
| 8/3 | Rhenium (Re) | 25 GPa | 2319 C | 234 |
| 10/5 | Re | 20 GPa | 2319 C | 612 |
| 14/8 “G2” | Graphite box | 13 GPa | 1200 C | 409 |
| 14/8 “HT” | Re | 15 GPa | 2000 C | 157 |
| 18/12 | Graphite | 10 GPa | 1500 C | 106 |
| *6-8 Kawai type assemblies for in-situ XRD* | | | | |
| 8/3 | Re/window | 25 GPa | 2000 C | 0 |
| 10/5 | Re/window | 21 GPa | 2000 C | 5 |
| 14/8 equatorial | Graphite | 15 GPa | 1200 C | 20 |
| 14/8 falling sphere | Graphite | 15 GPa | 2000 C | 50 |
| 14/8 “EC” | Re | 14 GPa | 2000 C | 67 |
| *DIA assemblies for in-situ XRD* | | | | |
| Standard (S-DIA) | Graphite | 8 GPa | 1200 C | 35 |
| Deformation (D-DIA) | Graphite | 8 GPa | 1200 C | 160 |
| Spherical DIA | Graphite | 8 GPa | 1200 C | 10 |
| GSECARS DIA assy’s | Graphite | 8 GPa | 1200 C | 100 |
| DELVE assemblies | TiB2/BN | 50 GPa (target) | 1200 C (target) | 40 |
| Other DIA (new trials) |  |  |  | 80 |
| TOTAL |  |  |  | 2085 |

Table 2: COMPRES Users of cell assemblies in iLab records in the period 2016-2017

|  |  |  |
| --- | --- | --- |
| **Name** | **Lab/PI** | **Institution** |
| Alwin James | Parise, John | Stony Brook University |
| Anne Pommier | Pommier, Anne | University of California at San Diego |
| Arianna Gleason | Gleason, Arianna | Stanford University |
| Bin Chen | Chen, Bin | University of Hawaii at Manoa |
| Megan Duncan | Fei, Yingwei | Carnegie Institution Geophysical Laboratory |
| Caleb Holyoke | Holyoke, Caleb | University of Akron |
| Dongli Yu | Yu, Dongli | Yanshan University |
| Eun Jeong Kim | Lee, Sung-Keun | Seoul National University |
| Gabriel Gwanmesia | Gwanmesia, Gabriel | Delaware State University |
| Haidong Zhang | Strobel, Timothy | Carnegie Institution for Science |
| Haiyan Chen | Weidner, Donald | Stony Brook University |
| Ulrich Haussermann | Haussermann, Ulrich | Stockholm University |
| Heather Kirkpatrick | Li, Jie | University of Michigan |
| Hong Yu | Yu, Hong | Starwave Technologies |
| Huiyang Guo | Gou, Huiyang | HPSTAR |
| Jeffrey Pigott | Van Orman, James | Case Western Reserve University |
| Jennifer Kung | Kung, Jennifer | National Cheng Kung University |
| Jeremy Wykes | Wykes, Jeremy | Macquarie University |
| Julien Chantel | Jing, Zhicheng | Case Western Reserve University |
| Kellye Pando | Righter, Kevin | JACOBS |
| Kirill Cherednichenko | Solozhenko, Vladimir | Laboratoire des Sciences des Procédés et des Matériaux |
| Kurt Leinenweber | Leinenweber, Kurt | Arizona State University |
| Kyusei Tsuno | Dasgupta, Rajdeep | Rice University |
| Lara Brown | Lesher, Charles | Aarhus University |
| Liping Wang | Wang, Liping | University of Nevada Las Vegas |
| Lucy Darago | Long, Jeffrey | UC Berkeley |
| Martin Bremholm | Bremholm, Martin | Aarhus University |
| Matthew Whitaker | Weidner, Donald | Stony Brook University |
| Mei Wang | Wang, Mei | TJ Pegasus |
| Michael Guerette | Strobel, Timothy | Carnegie Institution Geophysical Laboratory |
| Nadege Hilairet | Hilairet, Nadege | CNRS |
| Paul Raterron | Raterron, Paul | Brown University |
| Pinwen Zhao | Zhao, Pinwen | Jilin University |
| Richard Triplett | Weidner, Donald | Stony Brook University |
| Robert P. Rapp | Rapp, Robert P. | Australian National University |
| Samantha Clarke | Freedman, Danna | Northwestern University |
| Tony Yu | Wang, Yanbin | University of Chicago |
| William Durham | Durham, William | Massachusetts Institute of Techn |
| William Lee | Li, Pan | PES Enterprise Inc. |
| Jeremy Wykes | Wykes, Jeremy | Macquarie University |
| Xintong Qi | Li, Baosheng | Stony Brook University |
| Xiancheng Wang | Wang, Xiancheng | Institute of Physics, The Chinese Academy of Sciences |
| Yongtao Zou | Zou, Yongtao | Jilin University Superhard Materials |
| Yun-Yuan Chang | Hsieh, Wen-Pin | Academica Sinica, Taiwan |
| Zhenmin Jing | Jing, Zhenmin | China University of Geosciences (Wuhan) |
|  |  | Zhengzhou University |

**COMPRES Multi-Anvil Cell Assembly Project: Publication list for 2016 and 2017**

(**2016**)

Bollinger, C., P., Raterron, P. Castelnau, O., Detrez, F., Merkel, S. (2016) Textures in Deforming Forsterite Aggregates up to 8 GPa and 1673 K, Physics and Chemistry of Minerals 43, 409-417

Chantel, J.; Manthilake, G.; Andrault, D.; Novella, D.; Yu, T.; Wang, Y.B. (2016) Experimental evidence supports mantle partial melting in the asthenosphere. Science Advances 2, UNSP e16000246.

Clarke, S.M., M. Amsler, J.P.S. Walsh, T. Yu, Y. Wang, Y. Meng, S.D. Jacobsen, C. Wolverton, D.E. Freedman (2017) Creating binary Cu-Bi compounds via high-pressure synthesis: A combined experimental and theoretical study, Chemistry of Materials, 29(12), 5276-5285, DOI: 10.1021/acs.chemmater.7b01418.

Dobson, DP, Hunt, SA,  Ahmed, J, Lord, OT, Wann, ETH, Santangeli, J, Wood, IG, Vočadlo, L, Walker, AM, Mueller, HJ, Lathe, C and  Whitaker, M. (2016) The phase diagram of NiSi under the conditions of small planetary interiors. Phys. Earth Planet. Inter. 261 Part B 196-206

Guan, L.; Schwartz, M; Zhang, R.; Kroke, E. (2016) Polymer-precursor-derived (am-) SiC/TiC composites for resistive heaters in large volume multi anvil high pressure/high-temperature apparatus. High Pressure Research 36, 167-186.

He, Q.; Liu, X.; Li, B.; Deng, L. Liu, W.; Wang, L. (2016) Thermal equation of state of a natural kyanite up to 8.55 GPa and 1273 K. Matter and Radiation at Extremes [http://dx.doi.org/10.1016/j.mre.2016.07.003](https://urldefense.proofpoint.com/v2/url?u=http-3A__dx.doi.org_10.1016_j.mre.2016.07.003&d=DwMFaQ&c=l45AxH-kUV29SRQusp9vYR0n1GycN4_2jInuKy6zbqQ&r=RoQwO8CzF40xky0BqBEjdI5l_3fTf3m8ACXIZq4u2Q8&m=J760Am1mtj8zoBjDmyrsF8LdqIFkUdFEdKt1wKAz_8A&s=qVgEWWMG5jJx0gPL0XEq94ovpNYk6egeh_kSnyc6K1s&e=)

Hunt, S. A., Walker, A.M. and Mariani, E. (2016) In-situ measurement of fabric development rate in CaIrO3. Physics of the Earth and PlanetaryInteriors, 259, 91-104 doi:10.1016/j.pepi.2016.05.007

Kronbo, C.H.; Nielson, M.B.; Kevy, S.M., Parasiades, P.; Bremholm, M. (2016) High pressure structure studies of 6H-SrIrO3 and the octahedral tilting in 3C-SrIrO3 towards a post-perovskite. Journal of Solid State Chemistry 238, 74-82.

Liu, X., X. Chen, H. Ma, X. Jia, J. Wu, T. Yu, Y. Wang, J. Guo, S. Petitgirard, C. Bina, S. Jacobsen (2016) Ultrahard stitching of nanotwinned diamond and cubic boron nitride in C2-BN composite, Scientific Reports, 6, 30518, DOI: 10.1038/srep30518.

Raterron, P., Fraysse, G., Girard, J., Holyoke, C.W. III (2016) Strength of orthoenstatite single crystals at mantle pressure and temperature and comparison with olivine, Earth and Planetary Science Letters 450, 326–336.

Shofners, G.A.; Campbell, A.J.; Danielson, L.R.; Righter, K.; Fischer, R.A.; Wang, Y.B.; Prakapenka, V. (2016) The W-WO2 oxygen fugacity buffer (WWO) at high pressure and temperature: Implications for f(O2) buffering and metal-silicate partitioning. American Mineralogist 101, 211-221.

Spektor, K.; Nylen, J.; Mathew, R.; Eden, M.; Stoyanov, E.; Navrotsky, A.; Leinenweber, K.; Haussermann, U. (2016) Formation of hydrous stishovite from coestie in high-pressure hydrothermal environments. American Mineralogist 101, 2514-2524.

Wang, P.; Wang, Y.; Wang, L,; Zhang, Z.; Yu, X.; Zhu, J.; Wang, S.; Qin, J.; Leinenweber, K.; Chan, H.; He, D.; Zhao, Y. (2016) Elastic, magnetic and electronic properties of iridium phosphide Ir2P.Scientific Reports, 6, Article number: 21787; doi:10.1038/srep21787

Wang, S.M.; Yu, X.H.; Zhang, J.Z.; Wang, L.P.; Leinenweber, K.; He, D.W.; Zhao, Y.S. (2016) Synthesis, Hardness, and Electronic Properties of Stoichiometric VN and CrN. Crystal Growth and Design 16, 351-358.

Wang, YJ; Liu, ZTY; Khare, SV; Collins, SA; Zhang, JZ; Wang, LP; Zhao, YS (2016) Thermal equation of state of silicon carbide. Applied Physics Letters, 108, 061906; doi: 10.1063/1.4941797

T. Wu, T. A. Tyson, H. Chen, P. Gao, T. Yu, Z. Chen, Z. Liu, K. H. Ahn, X. Wang and S.-W. Cheong, “Pressure Dependent Structural Changes and Predicted Electrical Polarization in Perovskite RMnO3”, Journal of Physics Condensed Matter, 28 (2016) 056005

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**COMPRES multi-anvil project at the GSECARS Beamlines at the APS, Argonne National Lab (Year 2016-2017)**

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Kurt Leinenweber (ASU)

10/3/2017

GSECARS is a national user facility for earth science- related high pressure synchrotron research. For general high pressure beamline experiments, we provide the cell assemblies for user groups who have been granted beamtime to perform their experiments using our large volume presses (LVP) at our beamlines. The LVP group operates a 1000 t press in the 13-ID-D station and a 250 t press in the 13-BM-D station. The COMPRES multi-anvil project has been working closely with GSECARS and various user groups to develop cell assemblies that would fulfill the users‘ experimental requirements.

The T25 and the DDIA-30 are the two high pressure modules that users operate in the 1000 t press. We have relied heavily on the COMPRES cell assemblies since the Multi-anvil Cell Assembly Projected was commenced. Among the proposals that have been granted beamtime, 11 out of 16 general user proposals in Year 2016, and 13 out of 17 general user proposals in Year 2017 were using cell assemblies provided from the COMPRES multi-anvil project. The program has been providing cell assemblies for most of our users that operate the Kawai-type T25. The popular T25 beam-line cell assemblies include the 14/8, 10/5(beamline), and 8/3(beamline) cell assemblies. The 18/12, 14/8, 10/5(off-line), and 8/3(off-line) cell assemblies are popular for off-line sample sytheses. And starting from 2017 Cycle-1, the COMPRES-supported DELVE program has started testing various new high pressure cell assemblies using the dia-type DDIA-30 module at the GSECARS beamline. The goal is to push the routine pressure generation capability of the large volume press in the US to 50 GPa and above. The COMPRES multi-anvil project has been helping us develop and manufacture the cell parts for the DELVE project as well. So far, the project is running smoothly and we greatly appreciate the contribution of the COMPRES multi-anvil project.

Starting from 2016, GSECARS has also been partly relying on Kurt’s program to provide cell parts for routine high pressure experiments utilizing the DDIA module in the 250 t press in 13-BM-D. These cell assemblies are mostly for deformation experiments. The users have benefited greatly from the consistent quality of the materials and the precisely machined cell parts provided by the program.

The COMPRES cell assemblies have played a crucial role in many succesful high pressure experiments, resulting in important scientific observations. For instance, the cell assemblies have been used intensively for beamline X-ray diffraction studies, deformation experiments, density measurements, sound velocity measurments, viscosity measurements, etc (Chantel 2016a, 2016b). Some user groups also use the COMPRES cell assemblies for off-line sample synthesis work when the press is not in use with the synchrotron beam. This has been a very successful operation at GSECARS and has contributed to several new scientific discoveries (Clarke 2016, 2017; Liu, 2016). Attached is a list of publications and abstracts directly related to the COMPRES multi-anvil project that were performed at the GSECARS beamlines during 2016 and 2017.

Publications

Chantel, J., Z. Jing, M. Xu, T. Yu, Y. Wang (2016) Pressure dependence of liquidus and solidus in the Fe-P binary system determined by in-situ ultrasonics and X-ray diffraction in a multi-anvil apparatus, *Journal of Geophysical Research*, submitted.

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## **Multi-anvil synthesis of high density magnesium silicate samples for laser-driven shock experiments**

S.-H. Dan Shim, Jonathan Dolinschi, and Jacqueline Tappan (Arizona State University)

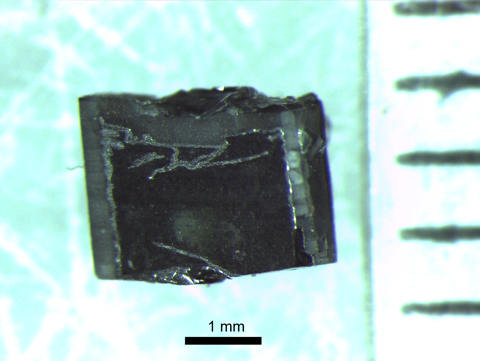
Recent developments in laser-driven shock technique enable us to obtain unprecedented number of data points at high pressure and high temperature during dynamic compression. Laser-driven shock can also generate pressures much higher than those in static compression (such as diamond-anvil cell). Some synchrotron facilities (such as Linac Coherent Light Source at Stanford lab and Advanced Photon Source at Argonne lab) now provide sufficient X-ray beam flux and time resolution for diffraction and spectroscopy measurements during dynamic compression.

Figure 1. Large wadsleyite sample synthesized in a 1000-ton multi-anvil press at ASU for laser-driven shock experiments.

Yet, an important limitation in shock compression is that pressure-temperature path (Hugoniot) is strongly constrained by the properties of starting materials. A few methods have been developed to overcome this limitation. One of the most powerful technique is to use a range of starting materials with different densities.

The Shim group has collaborated with scientists from Stanford University (PI: W. Mao), BGI (PI: T. Katsura), IMPMC (PI: G. Morard), LULI (PI: Ravasio), and SLAC (PI: Alonso-Mori) for studying melting behaviors of magnesium silicates during laser shock combined with X-ray diffraction and emission spectroscopy at LCLS. In August 2017, we have conducted our first laser-driven shock experiments at LCLS. In order to obtain large pressure-temperature coverage, the Shim group has synthesized a wide range of magnesium silicate materials in different densities. For high density samples, the Shim group has produced wadsleyite and majorite samples in multi-anvil press at ASU. For three months (May-July 2017), the Shim group was able to conduct a total of 14 multi-anvil syntheses and produce 11 high-quality samples. The samples are sufficiently large in size (up to 2.5 mm in diameter and 2 mm in height), such that approximately 100 thin disc shaped targets have been produced from these samples. For bridgmanite, the Shim group has collaborated with BGI (a total of 5 syntheses at BGI).

From September 2017, the Shim group has conducted a series of new multi-anvil synthesis for their next beamtime in Dec 2017 at LCLS. So far, the Shim group has produced a total of 3 wadsleyite samples and 5 bridgmanite samples at ASU. It is notable that using a 1000-ton press at ASU, the Shim group has been able to produce sufficiently large bridgmanite samples for shock targets. We note that all the multi-anvil synthesis has been conducted by ASU undergraduate students (Dolinschi and Tappan) through collaboration with Leinenweber.

Shim and Leinenweber plan to develop new sample configurations in multi-anvil press for effective production of shock targets. Shim also plans to synthesize a wide range of high density silicates for other types of extreme conditions experiments using the high power lasers combined with pulsed X-ray source at LCLS (USA) and PAL-XFEL (South Korea) in 2018.

**Research results by using** **COMPRES cell assemblies at the State Key Laboratory of Metastable Materials Science and Technology (MMST), Yanshan University, China (Year 2013-2017)**

Yonjung Tian, Dongli Yu, Julong He, Bo Xu, Zhongyuan Liu, Kun Luo, Quan Huang, Yufei Gao, Zhisheng Zhao (MMST)

Kurt Leinenweber (ASU)

11/14/2017

MMST is located at Qinhuangdao, a famous seaside resort city of China. As one of the state key laboratories in China, the MMST research focuses on the metastable materials. The major research topic includes theoretical design and experimental synthesis of novel metastable materials, and the high-pressure and high-temperature (HPHT) experimental methodology plays an important role in the synthesis of new metastable material. MMST is an international lab and our high-pressure group has established wide partnerships with lots of high-pressure institutions such as GSECARS and HPCAT in APS, Geophysical Laboratory of Carnegie Institution of Washington, HPSTAR in China, Technische Universität Darmstadt in Germany, and Luleå tekniska universitet in Sweden.

The China-type CS 1B (6 × 8 MN) cubic-anvil apparatus and the Kawai-type T25 (10 MN two-stage large-volume multi-anvil system) are the two main types of high-pressure apparatuses in our group, which can serve in a wide range of experimental conditions smoothly and steadily (P ≤ 25 GPa and T ≤ 2200 ℃). The routine HPHT experiments with pressure above 6 GPa are performed in T25 apparatus, which is same type one equipped in 13-ID-D at APS. We have relied heavily on the COMPRES cell assemblies, such as 14/8, 12/6, 10/5, and 8/3 cell assemblies. Start running from 2010, totaling 1108 experiments have been performed in our T25 apparatus. The 10/5 (totaling 672 experiments), and 8/3 (totaling 391 experiments) cell assemblies are popular for the sample syntheses. The 10/5 cell assemblies are usually used in pressures of 6-15 GPa, and the 8/3 cell assemblies are usually used in pressures of 15-25 GPa. Recently, we set up a new heating system with high-power supply in T25, the heating system becomes more stable and the maximum service temperature is easily up to 2200 ℃. The long, high efficient and stable operation of T25 benefited greatly from the consistent quality of the materials and the precisely machined cell parts of the COMPRES cell assemblies. So far, the success rate of experiments is nearly 100% and we greatly appreciate the contribution of the COMPRES multi-anvil project.

The COMPRES cell assemblies are the key to our successful high-pressure experiments, resulting in important progress in the synthesis of novel functional metamaterials. For instance, the cell assemblies have been used intensively to synthesize the nanotwinned diamond (nt-diamond) and cubic boron nitride (nt-cBN) with unprecedented hardness (nt-diamond: *H*v up to ~200 GPa; nt-cBN: *H*v exceeding 100 GPa), fracture toughness (nt-diamond: 9.7-14.8 MPa m0.5; nt-cBN: > 12 MPa m0.5), and thermal stability (nt-diamond: ~980 ℃; nt-cBN: ~1294 ℃) (Tian 2013, Huang 2014, Xu 2015a, 2015b, Zhao 2016). We also obtain several new scientific discoveries in phase transition (Wang 2015, Shu 2017), metastable structural materials (Hu 2017), and chemical reactions (Dai 2015). Attached is a list of publications directly related to the COMPRES cell assemblies that were performed at the Kawai-type T25 in MMST from 2013 and 2017.

Publications

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