

PRINCETON PLASMA PHYSICS LABORATORY

WEEKLY highlights



The PPPL Highlights for the week ending November 14, 2014, are as follows:

U.S. ITER FABRICATION (D. JOHNSON):

ORNL Engineer Miljko Bobrek presented information summarizing available FPGA hardware and software to the low field side reflectometer design team. He also presented Matlab simulations of FPGA determinations of phase from reflectometer raw data from DIII-D, provided by UCLA researchers.

USIPO Non-Nuclear Division Lead G. Murdoch and I&C Coordinator B. DeVan visited PPPL to discuss diagnostic instrumentation and control plans. They also met with diagnostic Control Account Managers, emphasizing the importance of CAMs in project control.

The IN-DA proposed a modification to their transmission line approach for the electron cyclotron emission (ECE) diagnostic. The design adopted in the conceptual phase featured a polarization splitter box, located just outside vacuum windows on the port plug closure plate, and illuminated by gaussian telescope located inside the port plug. The revised design relays the radiation quasi-optically through the bioshield, with the splitter box located in the port cell. Components in this location will be more readily maintained, and less vulnerable to radiation damage. This is of interest to the US, since the US-DA is integrating the port, and since the US is in charge of the port plug components for the ECE diagnostic.

NSTX (M. ONO):

The paper, "Broadening of divertor heat flux profile with increasing number of ELM filaments in NSTX" by J-W. Ahn (ORNL) et al, was published in Nuclear Fusion 54 (2014) 122004, and is available at <http://stacks.iop.org/0029-5515/54/122004>. It describes detailed divertor heat flux dynamics during the ELM observed in NSTX, and reports the increase of ELM heat flux profile width with the number of filamentary striations observed, i.e. profile narrowing is observed with zero or very few striations. The smaller number of filaments observed, compared to other tokamaks, is ascribed to the fact that NSTX lies on the long wavelength current-driven kink/peeling mode side with low n number ($n = 1-5$) while higher n ($n = 10-20$) peeling/ballooning mode is most commonly observed in many machines. As ITER is presently predicted to lie on the kink/peeling mode side, this work points to the need of detailed projections of the unstable modes expected in ITER.

Members of NSTX-U research and engineering team attended the American Nuclear Society Topical Meeting on the Technology of Fusion Energy (TOFE) on November 9-13, Anaheim, California. Three NSTX-U related invited talks were presented: "NSTX Upgrade for Establishing Physics and Technology Basis for FNSF" by M. Ono (PPPL), "Configuration Studies for an ST-based Fusion Nuclear Science Facility" by J. Menard (PPPL), and "The Present Status and Future Perspective of the Application of Liquid Metals for Plasma-Facing Components in Magnetic Fusion Power Reactors" by Yoshi Hirooka (NIFS). An oral presentation "Engineering Challenges and Opportunities with Liquid Metal Plasma-Facing Components" by M. Jaworski (PPPL), and poster presentations "Design Description for a Coaxial Helicity Injection Plasma Start-up System for a ST/FNSF" by Roger Raman (University of Washington) and "NSTX-U (Title III) Analysis Issues" by P. Titus" were also given. R. Maingi (PPPL) served as a Technical Program Committee Co-Chair of the conference.

Steve Sabbagh and Young-Seok Park of Columbia University continued running an experiment on the KSTAR tokamak attempting to access higher normalized beta. Record values of normalized beta for the device exceeding 4.3 were reached at low plasma internal inductance, yielding normalized beta to internal inductance ratios exceeding 6. These values are expected to be at least 50% over the $n = 1$ ideal no-wall beta limit computed from past analysis. Termination of these KSTAR plasmas at the highest normalized beta may be due to the appearance of a global MHD instability. Related analysis continues.

M. Ono (PPPL) visited UCLA on November 14. He met with the UCLA researchers including Professors Troy Carter, Walter Gekelman, Tony Peebles, and Mohamed Abdou. He toured the LAPD and related facilities and the Microwave laboratory. He gave a plasma physics seminar entitled "NSTX Upgrade for Establishing Physics and Technology Basis for FNSF".

Work has continued on optimizing the "Between and Among Shots Transp" runs (BEAST). Using a 1.1 sec duration NSTX H-mode as a base case, the execution time (wall time) of the TRANSP run has been reduced to 3.1 minutes when using a 16-processor GPU server when the beam time step is set to 20 milliseconds. With a beam time step of ten milliseconds, the wall time increases to 5.3 minutes. The 20-millisecond beam time step is acceptable for adequate statistics. On the present server, the times do not decrease with an increased number of CPUs. In fact, going to 32 processors increases the wall time.

The MPTS collection optics were installed after its modification for the new laser beam path and a sharp focus was obtained. A radial array calibration was performed. Assuming that stray laser light does not impede deployment, we expect to have 42 major-radius channels ranging from 39.4 centimeters to 155.4 centimeters. Work is continuing on the laser-beam path hardware. A theodolite has been installed in the new south-wall laser enclosure, which will be used to align the flight-tube baffles. Part of fiber-bundle protection hardware is inducing unwanted torque on elements of the collection optics and palliative measures are being considered.

ITER & TOKAMAKS (R. HAWRYLUK):

The review paper "Progress on ion cyclotron range of frequencies heating physics and technology in support of the International Tokamak Experimental Reactor," was published online in Physics of Plasmas. It can be downloaded at

<http://scitation.aip.org/content/aip/journal/pop/22/2/10.1063/1.4901090>. The abstract describes the scope: "Ion cyclotron range of frequency (ICRF) heating is foreseen as an integral component of the initial ITER operation. The status of ICRF preparations for ITER and supporting research were updated in the 2007 [Gormezano 2007] report on the ITER physics basis. In this report we summarize progress made toward the successful application of ICRF power on ITER since that time. Significant advances have been made in support of the technical design by development of new techniques for arc protection, new algorithms for tuning and matching, carrying out experimental tests of more ITER like antennas and demonstration on mockups that the design assumptions are correct. In addition, new applications of the ICRF system, beyond just bulk heating, have been proposed and explored."

R. Hawryluk visited the CNDA in Beijing, China and gave a presentation regarding the need for updating the costing algorithms used in power plant studies.

DIII-D (R. Nazikian):

W. Solomon and P. Snyder led experiments to try to expand the performance of the recently discovered Super H-mode regime [Solomon Phys Rev Lett. 113, 135001 (2014)]. The experiment used the previously developed technique of establishing QH-mode at low density and then raising density and betaN to try to access the predicted Super H-mode regime. The new experiments utilized feedback control of the Thomson density near the pedestal top, and also developed a new approach to move the Super H-mode channel toward the operating point by ramping the toroidal field and plasma current down. Future experiments will investigate Super H-mode pedestals in co-injected plasmas.

B. Grierson presented a Friday Science Meeting Talk at General Atomics describing the use of TRANSP for predictive simulations. TRANSP with the predictive transport solver (PT_SOLVER) can be used for transport and equilibrium model validation studies, as well as predicting shots that are planned for upcoming experimental campaigns and future devices.

Grierson presented TRANSP analysis and predictions of time-dependent torque rampdown in a DIII-D hybrid discharge using TGLF, capturing the gradual confinement degradation seen in the experiments over 2.5 seconds of controlled rotation slow-down. The results are in agreement with the ExB shear suppression of turbulence and its effect on confinement.

The copper pole shield plates have been plasma sprayed successfully and are now complete. About 75% of the TZM Moly tiles have been completed without any manufacturing issues. We expect the tiles to be completed next week with the final assemblies shipped to GA before Thanksgiving.

G. Kramer visited DIIID this week to work closely with B. Tobias and the ECE-I team on the analysis of BAAEs that are regularly observed in DIII-D. Kramer also worked with C. Muscatello on improving the MIR data analysis software. He also made progress on the implementation of RSAEs in the SPIRAL code, demonstrating that an analytic RSAE mode gave the same results as the analytic calculation.

The LGI system checkout continued this week in preparation for next weeks run. The final few signal related problems were resolved. The granule impeller was calibrated and operates up to 490 Hz. The system base pressure continues to get lower in the mid10⁻⁶ Torr range. D.

Mansfield and L. Roquemore are traveling to GA November 15-16 to set up the fast cameras used for pellet injection observation. A check out run using lithium is scheduled for the evening of November 18.

The neutral beam Local Control System hardware assembly and wiring is progressing. An FDR is scheduled for December 4 and a decision point on the installation is scheduled for December 22. We expect to be ready for installation by that date given the recent progress in hardware and wiring efforts.

Princeton PhD student Nikolas Logan visited DIII-D to participate in experiments this week. Logan has been applying eigspec and his own pyMagnetics package to document the variety of MHD mode activity in the low torque ITER baseline RMP experiments. He is also discussing possible extensions of TRANSP to include the second order neoclassical nonambipolar transport responsible for NTV torque.

C-Mod (R. Hawryluk):

Mechanical assembly of the ten-channel MSE background polychrometer proceeded smoothly this week and as of afternoon, of November 13, approximately 60% of the mechanical assembly is complete. An issue relating to the 'blocking' performance of the system's narrow bandpass optical filters was resolved with the vendor.

EAST (Hawryluk):

R. Hawryluk, H. Neilson and Y. Ren gave presentations at the US-PRC meeting in Nanjing, China and had many valuable discussions about future collaborations.

ADVANCED PROJECTS (D. GATES):

The journal "Physics of Plasmas" has accepted for publication a paper entitled "Verification of gyrokinetic microstability codes with an LHD configuration", by D. Mikkelsen and co-authors at NIFS, documenting benchmark calculations with the gyrokinetic codes GS2 and GKV-X. The benchmarks are based on an ion-ITB plasma in LHD, and there is very close agreement in the two independent calculations of the geometric coefficients in the gyrokinetic equation. The linear stability results for ITG modes (with adiabatic electrons) agree very closely for lower poloidal wavenumbers and agree to better than 10 percent at the peak growth rate, with larger differences at higher wavenumbers. Eigenfunctions agree well for all wavenumbers, with some isolated small differences.

Department collaborations were represented in several papers at the 21st Technology of Fusion Energy (TOFE) conference, held 10-12 November 2014 in Anaheim, CA. Included were an oral paper, "Wendelstein 7-X Inertially Cooled Test Divertor Unit Scraper Element Thermal Analysis," by P. Titus, et al. and poster papers "Disruption Analysis of the Proposed K-DEMO Inner Blanket Support Structure," by P. Titus et al.; "Engineering Design of an X-Ray Imaging Crystal Spectrometer for W7-X," by M. Mardenfeld, et al.; and "Instrumentation and Analysis of the W7-X Inertially Cooled Test Divertor Unit Scraper Element Design, by A. Lumsdaine (ORNL), et al. including several PPPL co-authors.

H. Neilson attended the U.S.-China Collaboration Workshop, held November 10-12 in Nanjing, China. Neilson made two presentations, "Stellarators and Magnetic Reconnection: Collaboration Opportunities," and "Reactor Engineering: Collaboration Opportunities." A number of collaboration tasks of mutual interest were identified in discussions with Chinese colleagues.

THEORY (A. BHATTACHARJEE):

On November 13, L. Zakharov presented a theory seminar on Tokamak Magneto-Hydrodynamics (TMHD) for understanding and simulations of plasma disruptions: The simplest set of Tokamak Magneto-Hydrodynamics (TMHD) equations, sufficient for disruption modeling and expandable to more refined physics, is presented. First, the TMHD introduces the 3-D Reference Magnetic Coordinates (RMC), which are aligned with the magnetic field in the best possible way. Being consistent with the high anisotropy of the tokamak plasma, RMC allow simulations at realistic, very high plasma electric conductivity and with high resolution of the plasma edge and resonant layers. Second, the TMHD splits the equation of motion into an equilibrium equation and the plasma advancing equation. This resolves the four-decade-old problem of Courant limitations of the time step in existing, plasma inertia driven numerical codes. Third, all TMHD equations have an energy principles, which lead to equations with positively defined symmetric matrices, thus, providing stability of numerical schemes.

On November 14, D. Gates presented Theory Department Research & Review Seminar on The Origin of Tokamak Density Limit Scalings: Density limits are reviewed and a mechanism for the origin of tokamak density limit scaling (i.e. the Greenwald limit) is presented. The mechanism is shown to be consistent with the observed phenomenology of disruptions at the limit as well as with the cases where density exceeds the limits. The status of current investigations are introduced, and plans and needs for future work will be discussed."

A paper entitled "Modification of the loss cone for energetic particles" authored by P. Porazik, J. Johnson, I. Kaganovich, and E. Sanchez, has recently been published online in Geophysical Research Letters, 10.1002/2014GL061869. The paper describes how the adiabatic loss cone is modified when higher order terms of the magnetic moment invariant are retained. It shows that injection along the field line is not the best choice to guarantee energetic particle loss in a mirror field, and that the optimal injection may require that the orientation with respect to the flux surface is also defined. The work was motivated by an experiment in which a relativistic electron beam is to be injected from aboard a spacecraft and subsequently detected in the Earth's atmosphere, for the purposes of mapping the Earth's magnetic field.

PLASMA SCIENCE AND TECHNOLOGY (P. EFTHIMION):

Off-site University Research: P. Efthimion and safety staff members W. Slavin and G. Anderson visited Professor Royce James (Commander) at the US Coast Guard Academy in New London, Connecticut. Commander James has a plasma physics laboratory for teaching Coast Guard cadets. He is now planning experiments using RF power and a Thomson Scattering laser system and asked the Off Site University Research (OSUR) for assistance on safety, and engineering and scientific practices. We also met and reviewed the work of the cadets working in the plasma

laboratory. Safety material and guidance were given to the Commander and possible follow-up assistance was discussed.

On November 13, Andrei Smolyakov from University of Saskatchewan, Canada presented seminar on Instabilities And Transport In Hall Plasmas With ExB Drift : Devices with stationary, externally applied, electric field which is perpendicular to a moderate amplitude magnetic field B_0 , are common in magnetically controlled plasmas. High interest applications involve Penning type plasma sources, magnetrons and magnetic filters, and electric space propulsion devices such as Hall thrusters. The electric field produces a stationary current due to the $E_0 \times B_0$ electron drift, while ions do not feel the magnetic field due to their large Larmor radius. Standard drift modes does not exist in such plasma but the ExB electron drift in inhomogeneous plasma and inertial (non-magnetized) ion response result in the so called anti-drift mode. The equilibrium electron flow destabilizes this mode and additional destabilization may come from the gradient of the magnetic field. The electron flow also results in instabilities of negative energy modes destabilized by dissipation due to collisions and sheath impedance. The characteristics of these instabilities and potential ramifications for Hall devices are discussed.

On November 14, Leonid Dorf from Applied Materials talked about Electron Beam Plasma Tool For Atomic Precision Etching: As the node size diminishes, microelectronics fabrication progressively requires atomic layer precision, so it becomes critical to accurately control ion energy during plasma processing. Damage caused by conventional plasma technologies (capacitively or inductively coupled plasmas) is becoming unacceptable for critical etch and clean applications. Using electron sheet beam parallel to the substrate surface to produce plasma in a processing chamber provides an order of magnitude reduction in electron temperature T_e (~ 0.3 eV) and ion energy E_i (< 2 eV without applied bias) compared to conventional plasma technologies, thus making electron beam plasmas an ideal candidate for processing features at 5 nm and below. In this presentation, we report processing results for a range of advanced plasma etching applications tested using the electron beam generated low T_e plasma. Using patterned wafers, we have developed low-bias power (0 – 10 W) processes resulting in infinite selectivity (as per high-resolution TEM images) of silicon nitride to silicon oxide and poly-silicon in fluorocarbon based chemistries. Such high selectivity can be attributed to the two phenomena: (1) at very low bias power, ion energy is sufficiently small to allow processing near the etch threshold, and (2) plasma ions and radicals in the electron beam generated plasma are produced by highly energetic (~ 2000 eV) electrons, such that the ratio between dissociation and ionization cross-sections for most gases differs considerably from that in conventional tools with chemical processes determined by 10-15 eV electrons. The latter results in weak dissociation of the fluorocarbon gas (CH_2F_2) and relatively low free fluorine concentration, which in turn leads to very low silicon etch rate. We have also investigated a nitride spacer application, in which 20 nm nitride layer deposited conformly over a silicon fin needs to be etched away to produce straight side walls for further double patterning (as one application). Our results indicate that using the electron beam plasma provides suitably small footing with a reasonably small slant angle of the shoulder, at the same time being selective to the underlying silicon layer. Accurate analysis of several time-series of TEM images allowed characterization of lateral and vertical etch processes over a range of operating conditions, such as the bias power and the beam current. Initial studies also indicate excellent loading characteristics, even at high bias power, which again can be attributed to unique chemical composition of the processing gas in the electron beam generated plasma.

ENGINEERING AND INFRASTRUCTURE (M. WILLIAMS):

NSTX Upgrade (R. Strykowski, E. Perry, L. Dudek, T. Stevenson):

Construction: Neutron calibration in the NSTX vacuum vessel has been successfully completed. The MPTS in-vessel work has been completed. Diagnostics, windows and blank offs are being installed on the vessel to support closing the vessel in the next few days. There are four crews fitting up and installing the CHI, PF, OH and TF bus - bus inside the umbrellas is the priority since it must be done before other tasks can start inside the umbrellas. Glow discharge terminations at the vessel have been completed. Re-installation of cables and lines to the TIVs and shutters is underway. Instrumentation wiring inside the umbrellas (both vacuum side and air side of the centerstack) is being installed. Organ pipe extensions are being installed in the upper umbrella. The TF current monitor has been re-installed. The NSTX Test Cell will be closed on November 20 for the re-installation of the NB1 duct.

CS Upgrade: Insulation of the PF Bus bars continued in the CS Winding area. Cleaning and silver-plating of the TF Flex connectors continued in winding area. The conceptual design of the OH Water Heating system progressed with receipt of quotes for both tankless and tank water heaters. A supplier of custom made non-conductive, high pressure, high temperature hosing was also located. A sample of hosing was ordered with delivery expected the week of November 17 for testing. A peer review of the conceptual design is being planned for the week of November 17 to select the best concept.

NBI Upgrade: Services work continued on BL2 source SF6 delivery line installation. Reactivation of N4ABC power supplies was completed and open circuit voltage was applied to the switchyard, surge rooms, and modulator/regulators using LCCs. Controls work continues with installation of cable, trays, and terminations in NTC and gallery. Progress continues on PLC software pages. Cryogenics maintenance and repairs in preparation for operations continues. Development of NB procedures continues. Preparations have started for the Readiness Review scheduled during the month of December.

Installation of the BL1 duct and closure of the VV may occur as early as the week of November 17. Afterwards, there are plans to pump down BL2 for initial leakchecking. A VV pumpdown is also planned.

Digital Coil Protection System: Construction activities for the DCPS system have been completed and the core DPCS code has been tested. The Autotester is operational. Hardware preoperational test procedures have been written, approved, and executed with additional testing planned. Therefore the DCPS system has moved from construction phase to operations phase and will continue with preparations for dummy load testing of rectifiers.

PUBLICATIONS:

Ahn, J-W. (ORNL); Maingi, R.; Canik, J.M.; Gan, K.F.; Gray, T.K.; and McLean, A.G., "Broadening Of Divertor Heat Flux Profile With Increasing Number Of ELM Filaments in NSTX," Nuclear Fusion 54 (2014) 122004, <http://stacks.iop.org/0029-5515/54/122004>.

Wilson, J.R.; and Bonoli, P.T., "Progress On Ion Cyclotron Range Of Frequencies Heating Physics And Technology In Support Of The International Tokamak Experimental Reactor," Physics of Plasmas 22, 021801 (2015); <http://dx.doi.org/10.1063/1.4901090>

Porazik, P.; Johnson, J.; Kaganovich, I.; and Sanchez, E.; "Modification Of The Loss Cone For Energetic Particles," Geophysical Research Letters, 10.1002/2014GL061869.

INVITED TALKS:

Ono, M., "NSTX Upgrade for Establishing Physics and Technology Basis for FNSF," American Nuclear Society Topical Meeting on the Technology of Fusion Energy, Anaheim, California

Menard, J., "Configuration Studies for an ST-based Fusion Nuclear Science Facility," American Nuclear Society Topical Meeting on the Technology of Fusion Energy, Anaheim, California

Hirooka, Y. (NIFS), "The Present Status and Future Perspective of the Application of Liquid Metals for Plasma-Facing Components in Magnetic Fusion Power Reactors," American Nuclear Society Topical Meeting on the Technology of Fusion Energy, Anaheim, California

This report is also available on the following web site:
<http://www.pppl.gov/publication-type/weekly-highlights>