Electron Bernstein Wave Coupling, Propagation and Current Drive in National Spherical Torus Experiment (NSTX) and Pegasus

G. Taylor[1], T.S. Bigelow[2], J.B. Caughman[2], M.D. Carter[2], S. Diem[1], P.C. Efthimion[1], R.A. Ellis[1], N.M. Ershov[3], R.J. Fonck[4], E. Fredd[1], G.D. Garstka[4], R.W. Harvey[5], J. Hosea[1], F. Jaeger[2], B. LeBlanc[1], B.T. Lewicki[4], C.K. Phillips[1], J. Preinhaelter[6], A.K. Ram[7], D.A. Rasmussen[2], A.P. Smirnov[3], J. Urban[6], J.B. Wilgen[2], J.R. Wilson[1]
email: gtaylor@pppl.gov
[1]Plasma Physics Laboratory, Princeton University, Princeton, NJ 08543, USA
[2]Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA
[3]Moscow State University, Moscow, Russia
[4]University of Wisconsin, Madison, WI 53706, USA
[5]CompX, Del Mar, CA 92014, USA
[6]Czech Institute of Plasma Physics, Prague, Czech Republic
[7]Plasma Science and Fusion Center, MIT, MA 02139, USA

The spherical torus (ST) can be an attractive candidate for a high β fusion reactor only if the plasma can be sustained non-inductively. While the bootstrap effect and neutral beams can generate most of the plasma current, in order to stabilize the plasma some plasma current may need to be driven off-axis by an external radiofrequency source. The "overdense" ($\omega_{pe}>>\omega_{ce}$) character of the ST plasma precludes electron cyclotron current drive but allows the use of electron Bernstein wave current drive (EBWCD). EBWs freely propagate in overdense plasma and strongly damp at electron cyclotron resonances. EBW emission (EBE) diagnostics, 3-D EBW ray-tracing and Fokker-Planck EBWCD modeling are being employed to study EBW coupling, propagation and EBWCD physics in NSTX and the Pegasus ST. This research is motivated by a long-term goal to implement a multi-megawatt EBWCD system on NSTX. EBE measurements and modeling support a EBWCD system design using efficient EBW coupling via obliquely launched, elliptically polarized microwaves and Ohkawa EBWCD to generate current well off-axis in a region dominated by magnetically-trapped electrons [1].

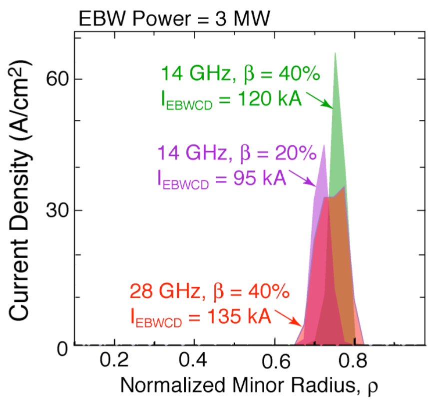

Fig. 1 Calculated EBWCD profiles versus normalized minor radius for NSTX.

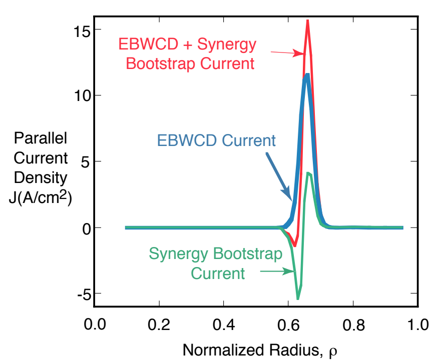

Fig. 2 EBWCD current density profile including bootstrap synergy for 1 MW of 28 GHz EBW power in a β =40% NSTX plasma.

Modeling of EBWCD at 14 and 28 GHz in NSTX plasmas predicts current drive efficiencies of 40-50 kA/MW and current densities peaking at a normalized minor radius ~ 0.7 outboard of the magnetic axis (Fig. 1) [2]. There is a synergistic increase in bootstrap current due to enhanced EBW-induced pitch angle scattering that can significantly change the radial profile of the EBW-driven current (Fig. 2) [3].

Obliquely viewing, dual-polarization radiometry has been employed on NSTX to evaluate the coupling efficiency of thermal EBE [4,5]. An EBW coupling efficiency of 80±20% at 16.5 GHz was achieved, in good agreement with the 65% coupling efficiency predicted by a model that included a 1-D full wave calculation of EBW mode conversion, radiometer antenna pattern modeling and 3-D EBW ray tracing and deposition (Fig. 3). The polarization of the measured EBE was consistent with the elliptical polarization predicted by the modeling. EBE coupling experiments up to 40 GHz are now being conducted on NSTX. Analysis of 24-32 GHz EBE data shows only ~20% EBW coupling efficiency from some H-mode plasmas and suggests that EBW loss due to collisions can become significant when the EBW mode conversion layer lies near the foot of the H-mode pedestal, a region where T_e can be less than 20 eV.

EBW experiments in the Pegasus ST with up to 1 MW of 2.45 GHz power will investigate nonlinear edge effects, power deposition and EBWCD. Modeling predicts an EBWCD efficiency of 20 kA/MW and an EBW-driven current density of 20-100 kA/cm^2 on axis [6]. Under some conditions, the current direction is predicted to change with current profile shape (Fig. 4), this will be investigated in the Pegasus experiments.

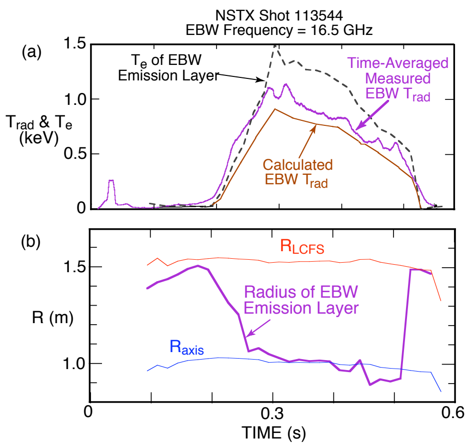

Fig. 3 (a) Evolution of the measured 16.5 GHz EBW radiation temperature (T_{rad}) on NSTX (purple) agrees well with the calculated T_{rad} (brown). EBW T_{rad} ~ 80% of T_e of the EBW emitting layer (black dash) (b) EBE is emitted from the magnetic axis of NSTX from 0.25 to 0.5 s.

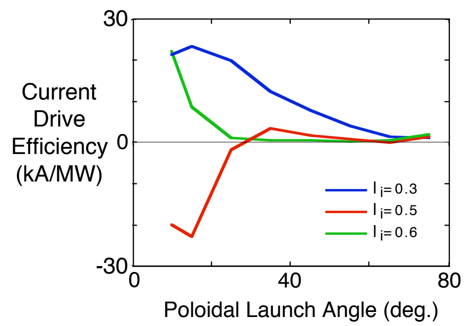

Fig. 4 Plot of EBWCD efficiency versus poloidal launch angle for Pegasus plasma cases with I_{tf} = 150 kA and various current profiles having l_i = 0.3, 0.5 and 0.6. The current drive direction may be sensitive to changes in the current profile shape.

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