**Plasma initiation and startup studies in the DIII-D tokamak with second harmonic EC assist**

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## Abstract

Second harmonic X-mode (X2) electron cyclotron (EC) heating has been used in DIII-D in conjunction with plasma initiation and current rampup. Although the toroidal inductive electric field $\left(E_\phi\right)$ in DIII-D is high enough (0.9–1.0 V/m) to allow robust startup without EC assist, startup in fusion devices such as ITER will have lower fields $\left(E_\phi = 0.3 \text{ V/m}\right)$ and EC assist can provide a reproducible breakdown and an increased margin for burnthrough of low $Z$ impurities. ECH, applied before the inductive electric field, is used to separate the various phases of plasma breakdown and startup, and is defined as pre-ionization. Pre-ionization first occurs near the X2 resonance location and then expands in the vessel volume. Perpendicular launch $\left(k_{||} = 0\right)$ is found to produce the strongest pre-ionization. The power threshold for pre-ionization can be reduced by optimizing prefill and vertical field, although the lowest power threshold is not at the optimum value for *Ohmic* startup alone. An orbit following code confirms that cold electrons (0.03 eV) can be sufficiently heated by ECH to energies above the threshold of ionization of hydrogen. This code predicts heating in new tokamaks such as KSTAR and ITER to energies where pre-ionization can occur. The ITER startup scenario has been simulated in DIII-D experiments and X2 ECH assist has been applied at reduced toroidal loop voltage to assist burnthrough and plasma current rampup.