Second Harmonic ECH preionization with 7 pairs PF coil scenario for KSTAR

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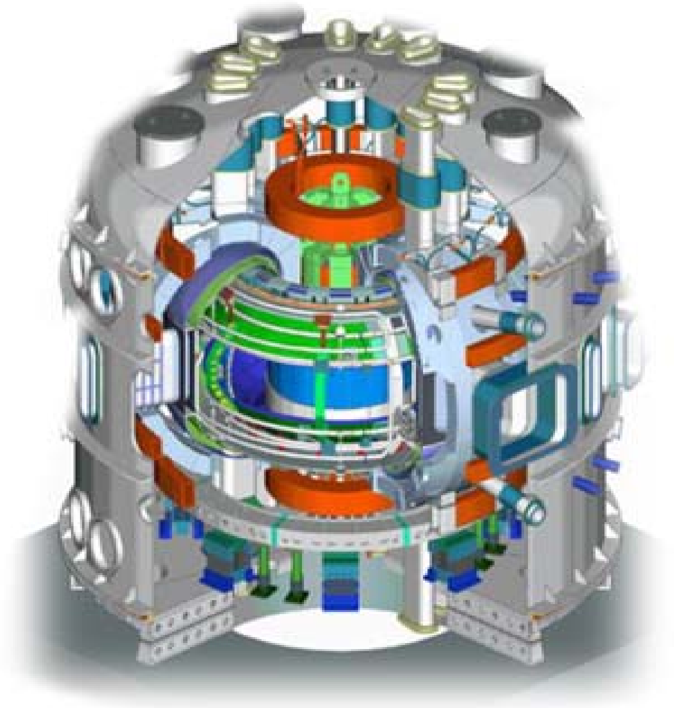
Abstract

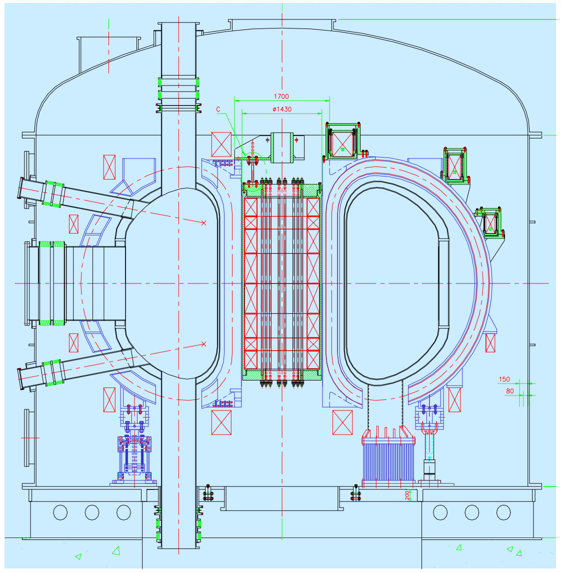
In the initial phase of KSTAR operations, the toroidal magnetic field is planned to be 1.5 T at the tokamak center. In this case, the electron cyclotron frequency is 42 GHz., and the operating frequency of the ECH pre-ionization system is 84 GHz, corresponding to the second harmonics. We modified the pre-ionization code with 7 pairs of poloidal coils. Through the pre-ionization simulation, we obtained the dependence of the loop voltage, electron temperature, and plasma currents for several input parameters in the second harmonic ECH pre-ionization. It is compared to the results of the fundamental harmonic ECH pre-ionization.

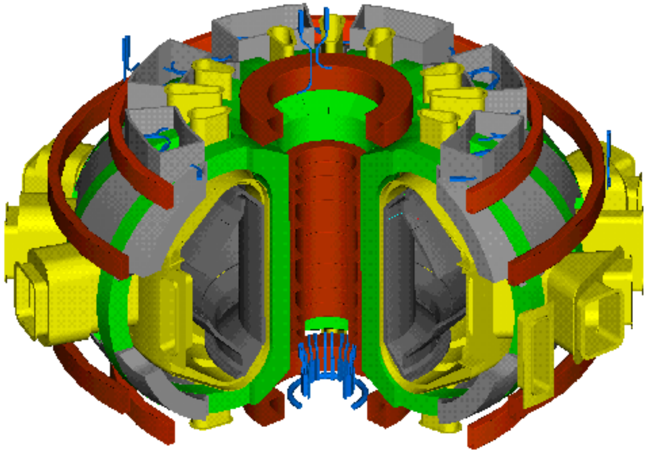


KSTAR Target Operation Modes

Operation Phase	Target Operation Modes	
First Plasma	1.0 ECH-assisted 5 V-inner start-up mode	B_o = 1.5 T, I_p = 100 kA
Ohmic Plasma	2.0 ECH-assisted 6 V-outer start-up mode	B_o = 3.5T, I_p = 2 MA
Baseline Plasma	3.0 Ohmic + NBI mode	B_o = 3.5T, I_p = 2 MA
	3.1 Ohmic + NBI + RF mode	
	3.2 Ohmic + NBI + RF + MW mode	P_{NBI} = 8 MW, P_{RF} = 6 MW
	3.3 Extended mode	P_{MW} = 1.5 MW
Upgrade Plasma	4.0 Low-beta Reverse-shear mode	
	4.1 Low-beta High-li mode	B_o = 3.5 T, I_p = 2 MA
	4.2 Low-beta H-mode	
	4.3 High-beta Reverse-shear mode	P_{NBI} = 16 MW, P_{RF} = 12MW
	4.4 High-beta High-li mode	P_{LH} = 3MW, P_{ECH} = 3 MW
	4.5 High-beta H-mode	
	4.6 Full performance mode	

PF coil structure

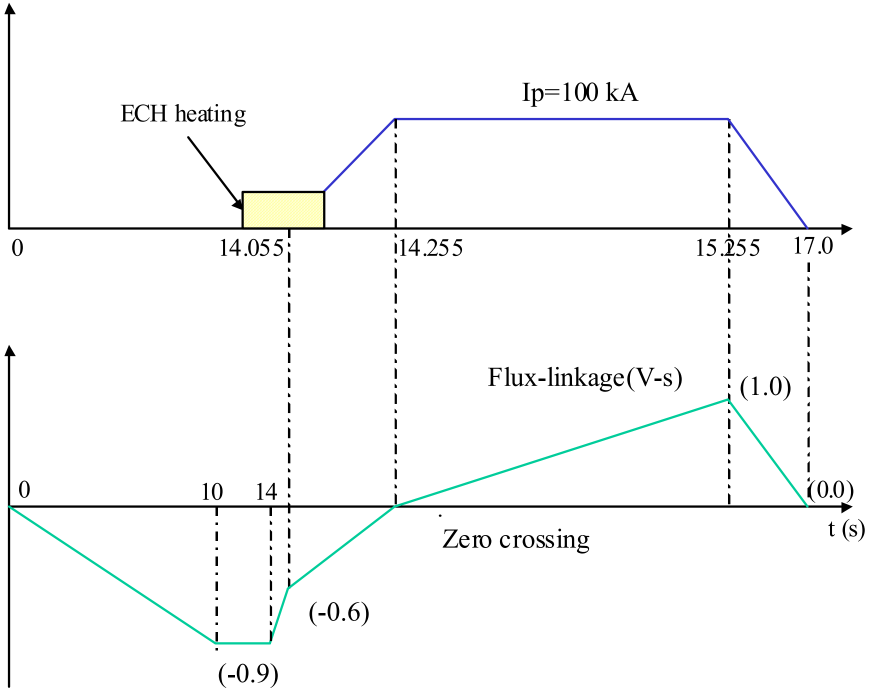


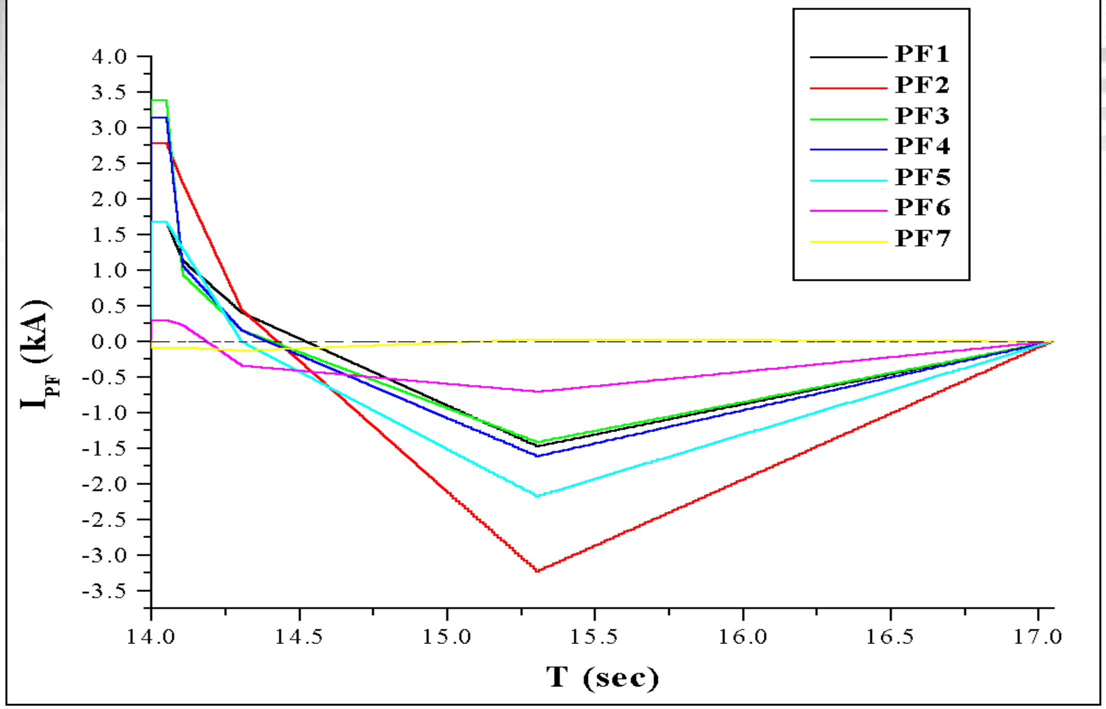


(Unit : mH)

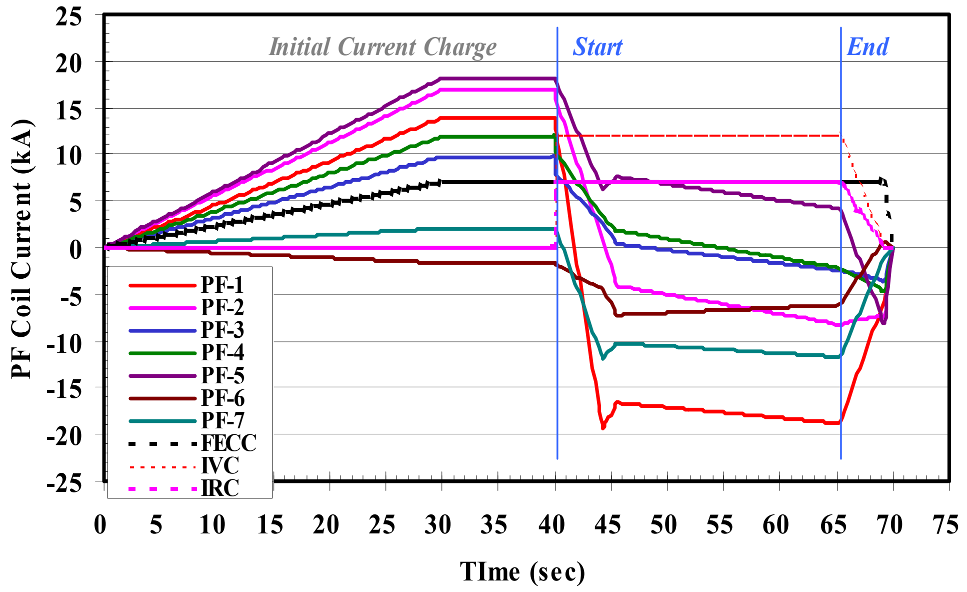
	PF1	PF2	PF3	PF4	PF5	PF6	PF7	PLA
PF1	85.6	26.55	5.96	5.28	7.45	7.13	8.3	0.11
PF2	26.55	44.98	12.56	9.18	7.85	5.81	6.47	0.073
PF3	5.96	12.56	13.43	10.38	5.3	2.96	3.13	0.037
PF4	5.29	9.18	10.38	26.93	10.96	4.48	4.52	0.031
PF5	7.45	7.85	5.3	10.96	327.4	37.32	31.21	0.135
PF6	7.13	5.81	2.95	4.48	37.31	199.36	99.1	0.219
PF7	8.3	6.47	3.13	4.52	31.2	99.1	316.45	0.284
PLA	0.11	0.073	0.037	0.031	0.135	0.219	0.284	0.003

KSTAR Operation Scenario (First Plasma Phase)





PF Coil Current (kA) vs. time (sec)



Input parameters

1. A major radius; R = 180 cm.
2. A minor radius; a = 50 cm.
3. An error field range; $B_{err} = 0.1 \sim 4$ (mT)
4. An initial neutral density; $n_o = 0.2\times10^{13} \sim 3\times10^{13}$ (cm^{-3}).
5. RF pulse duration; $T_{RF} = 0.2s$.
6. A magnetic field; $B_o = 1.5$ T.
7. A carbon impurity fraction; $f_{ci} = 0.01$
8. An oxygen impurity fraction f_{oi} is always set to 2 times f_{ci}.
9. All wave propagates X-mode.

Pre-ionization code model

Continuity equation

$$\frac{dn_e}{dt} = n_e v_{ion} - n_e (v_{err} + v_{dr} + v_{diff})$$

where v_{ion} *is the ionization rate,*

v_{err} *is the loss rate due to error field,*

v_{dr} *is the loss rate due to the toroidal drift*

and v_{diff} *is the loss rate due to the diffusion.*

→ n_e

Particle balance

$$\frac{dn_o}{dt} = -\frac{dn_e}{dt}$$

→ n_o

Energy balance

$$\frac{dU_e}{dt} = \frac{P_{ECH} + P_{OH} - P_{RAD}}{V} - U_e (v_{err} + v_{dr} + v_E) - \frac{1}{V}(P_{EQU} + P_{BREM} + P_{IRAD})$$

$$\frac{dU_i}{dt} = \frac{1}{V}(P_{EQU} - P_{CX}) - U_i v_E$$

→ U_e, U_i, T_e

Circuit equation

$$-\sum_{n=1}^{8} M_{n8} \frac{dI_n}{dt} - I_8 R_p = 0 \quad \Rightarrow \quad dI_8 = \frac{-\sum_{n=1}^{8} M_{n8} \frac{dI_n}{dt} - I_8 R_p}{M_{88}} \times dt$$

V_{loop} ***(loop voltage)*** $= -\sum_{n=1}^{7} M_{n8} \frac{dI_n}{dt}$

V_{resis} ***(resistive voltage)*** $= -I_8 R_p$

where $n = 1 \sim 7$ ***for the 7 pairs of PFcoil and*** $n = 8$ ***for the plasma,***

R_p ***is teh plasma resistence***

and the M_{n8} ***is the mutual inductances between PF coils and plasma.***

→ V_{loop}, V_{resis}, I_p

Results of the code calculation

1. Temporal behavior

Second harmonic case

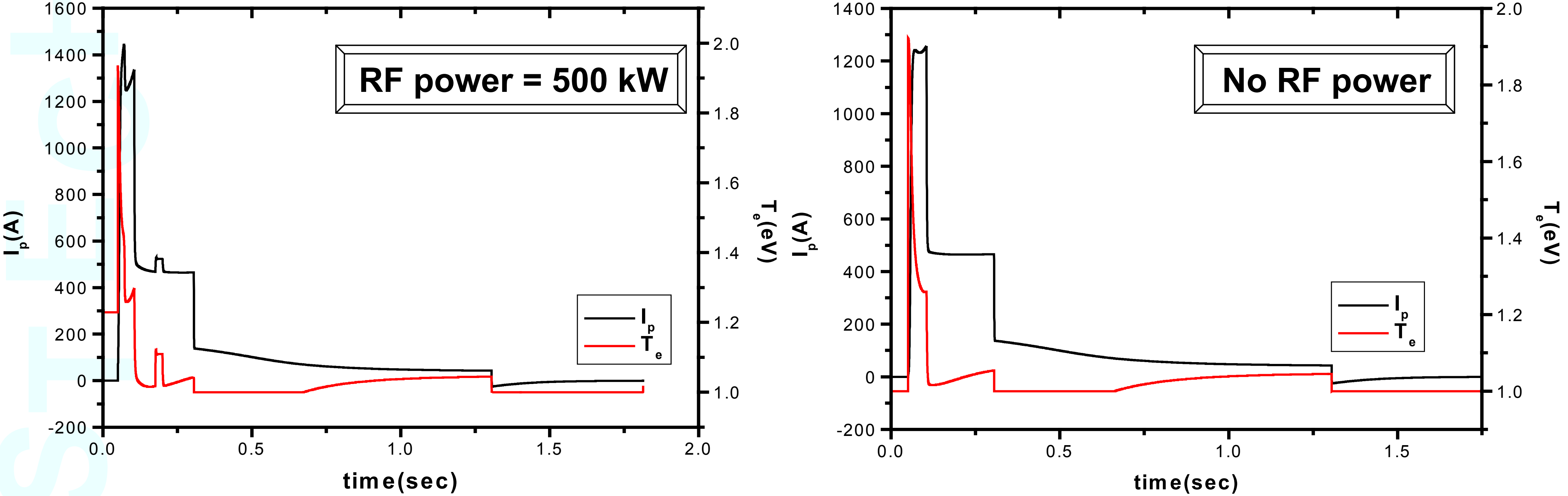


FIG. 1-1. Plots of the plasma current I_p and the electron temperature T_e as a function of time.

The RF power 500 kW is applied for 0.2 sec, and the Ohmic heating is applied at 50 msec. The parameters are P_{RF} = 500 kW, B_{err}=1 mT, f=84 GHz, $n_o = 1.0\times10^{13}\ cm^{-3}$, $n_e(0) = 1.0\times10^{9}\ cm^{-3}$

Fundamental harmonic case

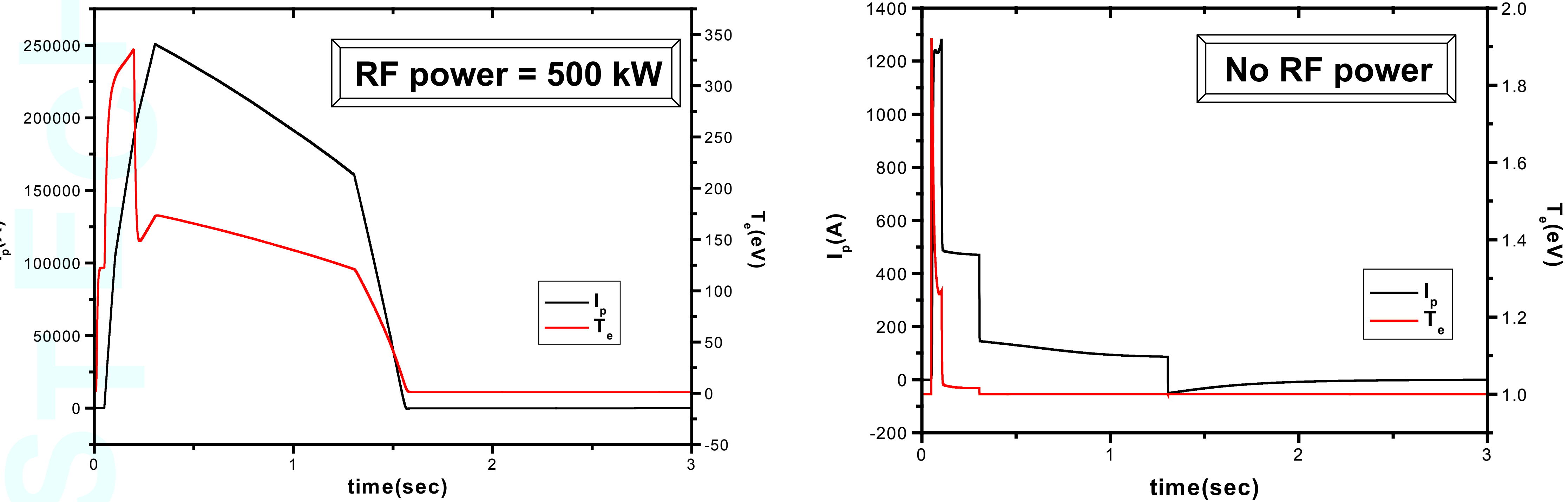


FIG. 1-2. Plots of the plasma current I_p and the electron temperature T_e as a function of time.

The RF power 500 kW is applied for 0.2 sec, and the Ohmic heating is applied at 50 msec. The parameters are P_{RF} = 500 kW, B_{err}=1 mT, f=84 GHz, n_o = 1.0×10^{13} cm^{-3}, $n_e(0)$ = 1.0×10^{9} cm^{-3}

2. Error field scan

Second harmonic case

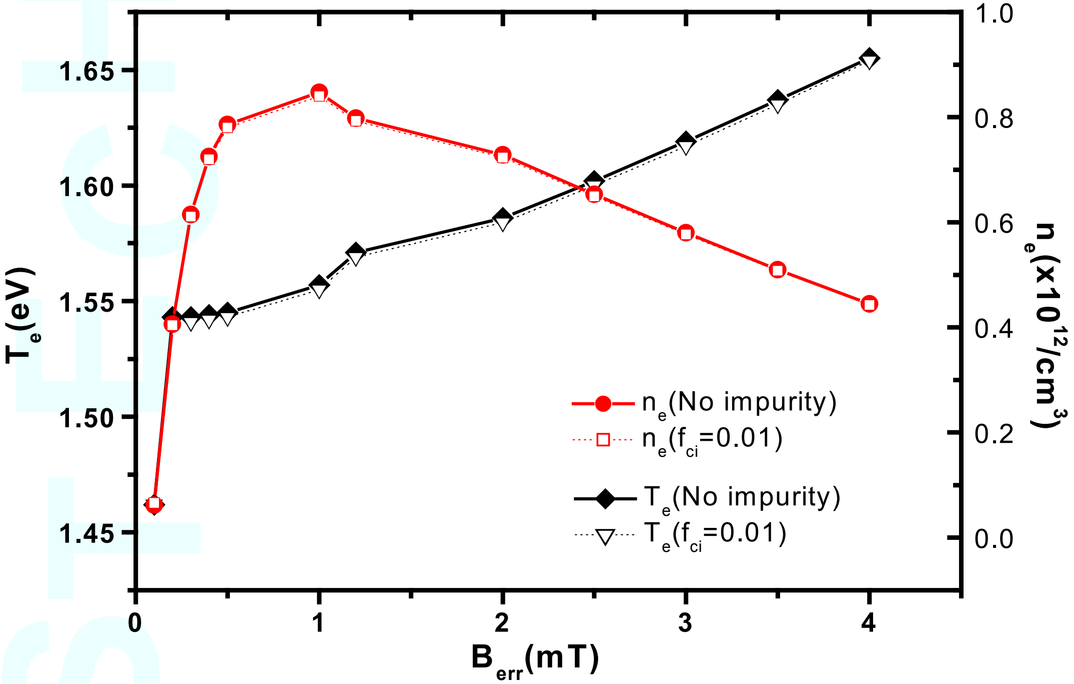


FIG. 2-1. (a) The electron temperature T_e and electron density n_e at 60 ms, plotted as a function of the error field B_{err}.

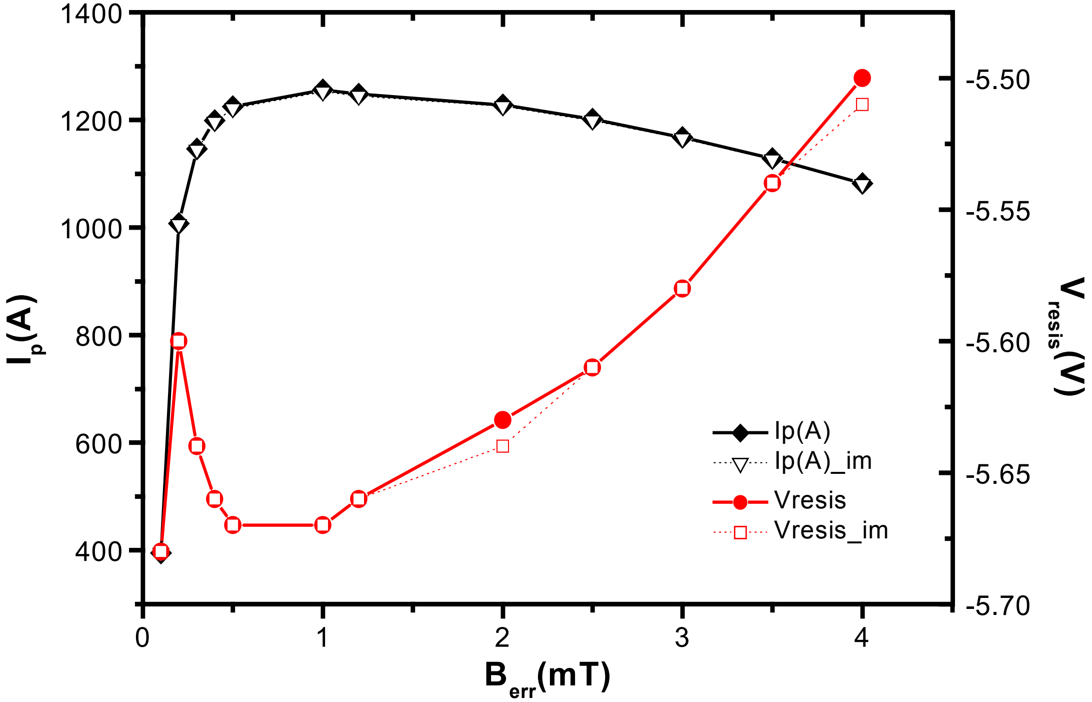


FIG. 2-1. (b) The plasma current I_p and resistive voltage V_{resis} at 60 ms, plotted as a function of B_{err}.

Fundamental harmonic case

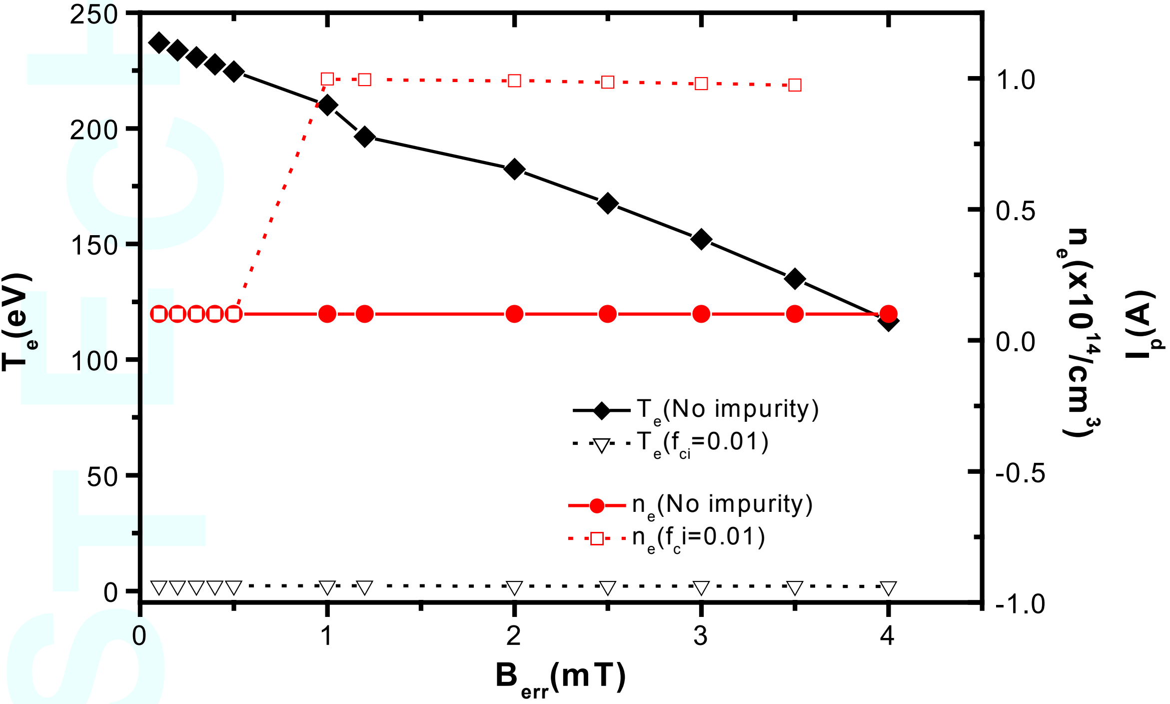


FIG. 2-2. (a) The electron temperature T_e and the electron density n_e at 60 ms, plotted as a function of the error field B_{err}.

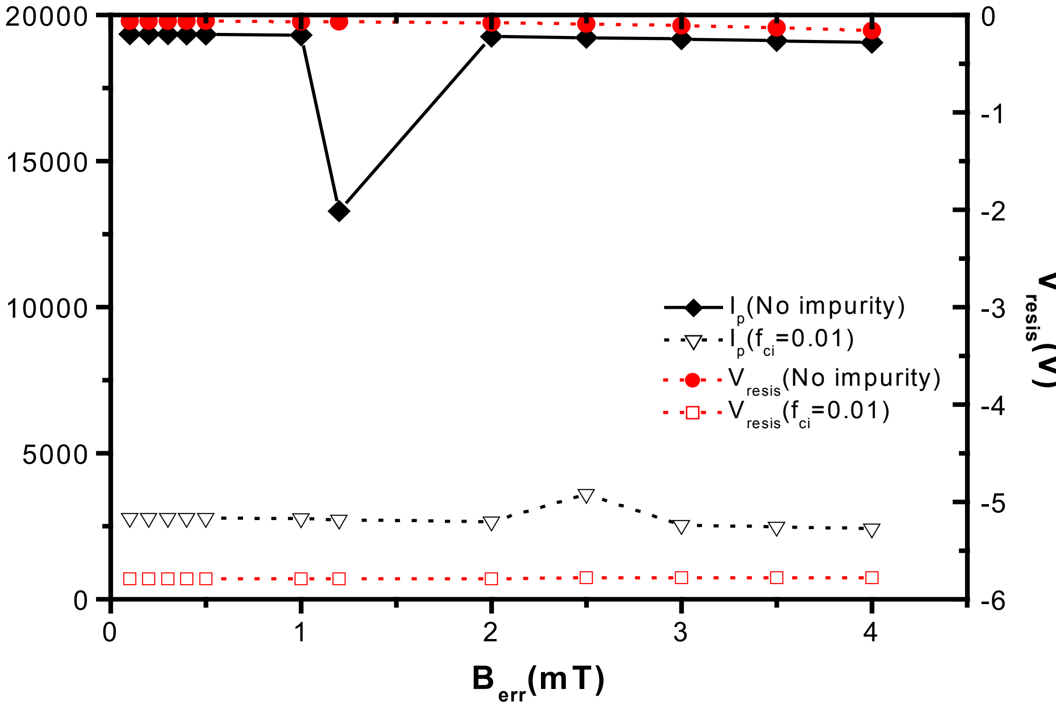


FIG. 2-2. (b) The plasma current I_p and resistive voltage V_{resis} at 60 ms, plotted as a function of B_{err}.

3. Neutral density scan

Second harmonic case

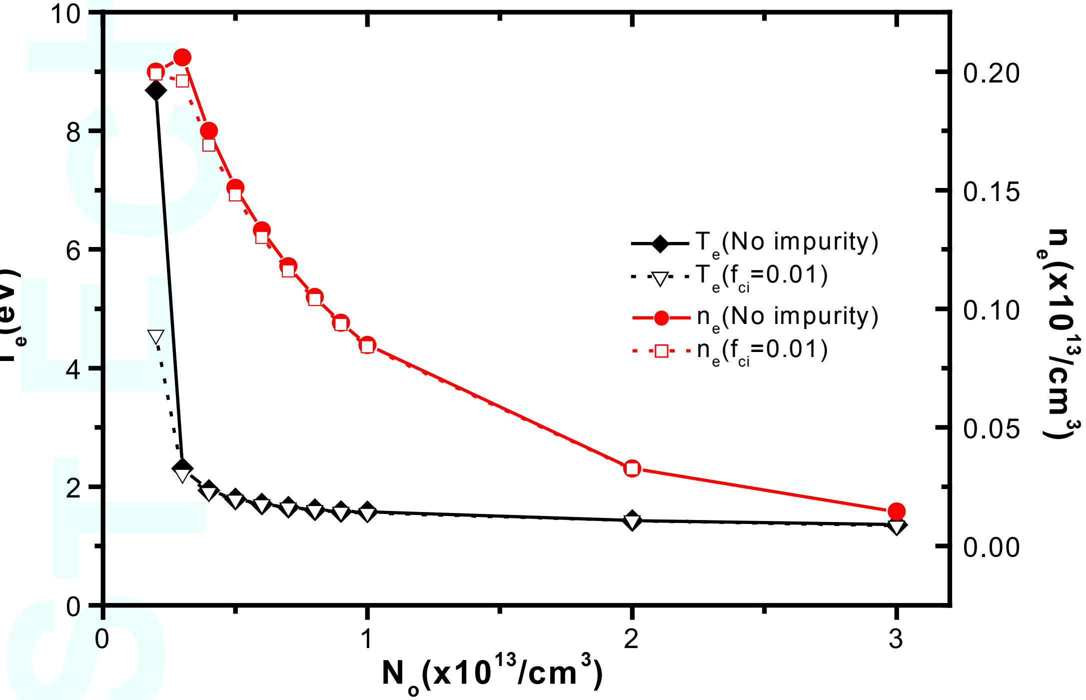


FIG. 3-1.(a) The electron temperature T_e and electron density n_e at 60 ms, plotted as a function of initial neutral density n_o.

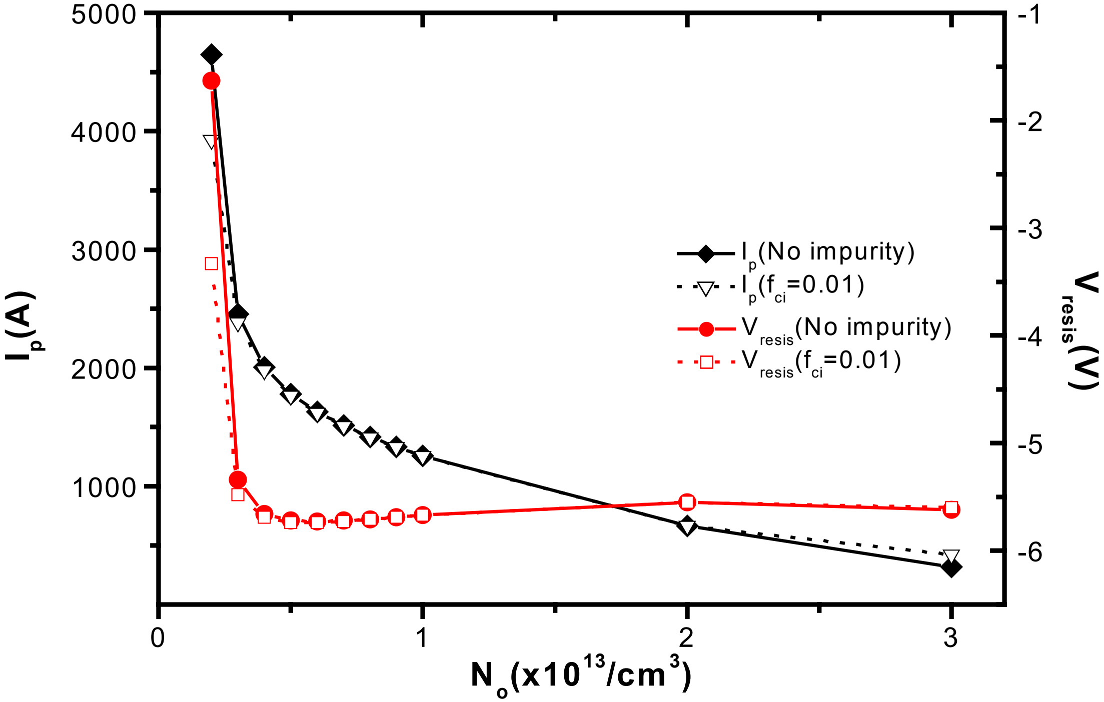


FIG. 3-1.(b) The plasma current I_p and resistive voltage V_{resis} at 60 ms, plotted as a function of initial neutral density n_o.

Fundamental harmonic case

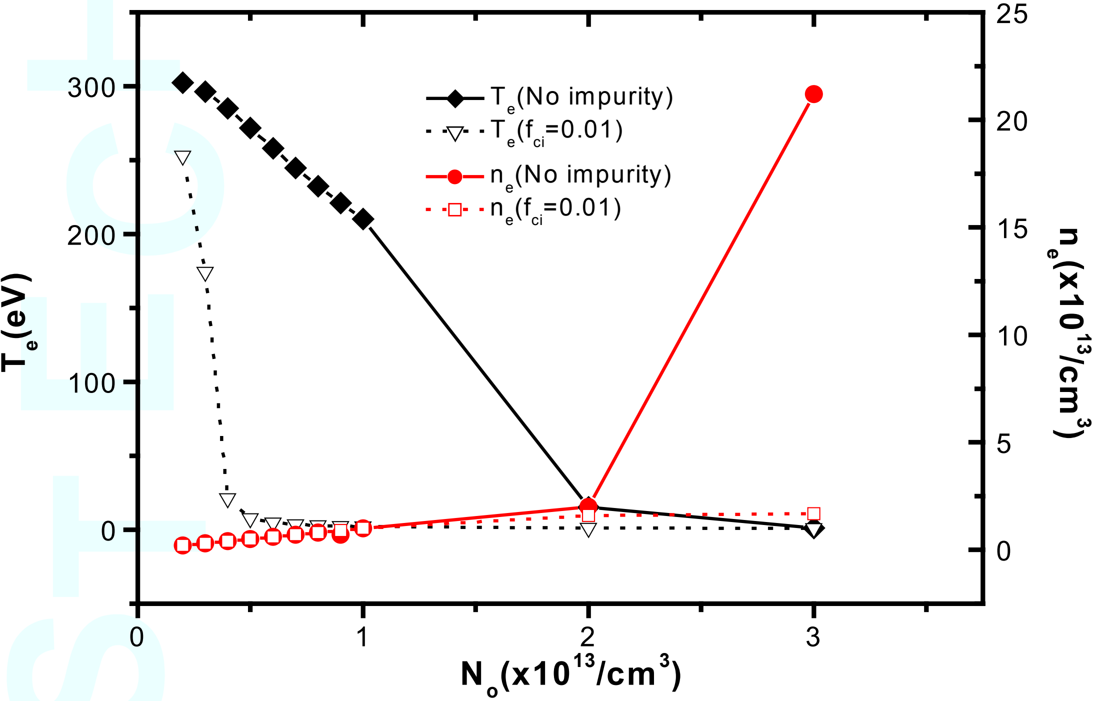


FIG. 3-2. (a) The electron temperature T_e and electron density n_e at 60 ms, plotted as a function of initial neutral density n_o.

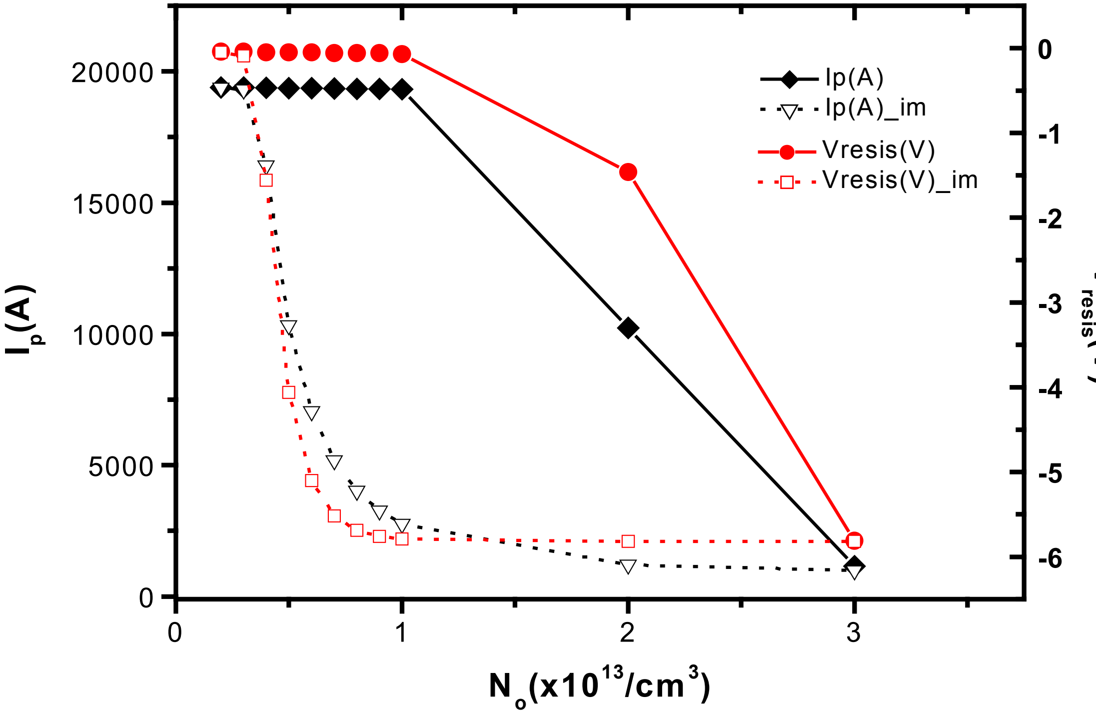


FIG. 3-2. (b) The plasma current I_p and resistive voltage V_{resis} at 60 ms, plotted as a function of initial neutral density n_o.

4. RF power scan

Second harmonic case

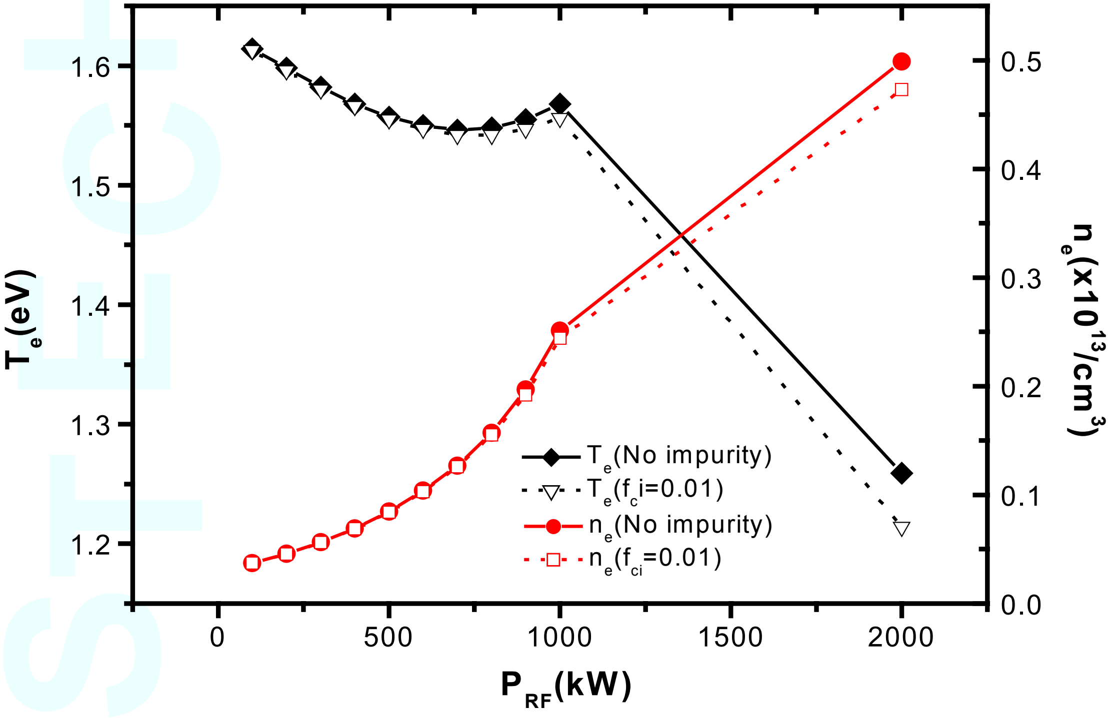


FIG. 4-1. (a) The electron temperature T_e and electron density n_e at 60 ms, plotted as a function of the RF power P_{RF}

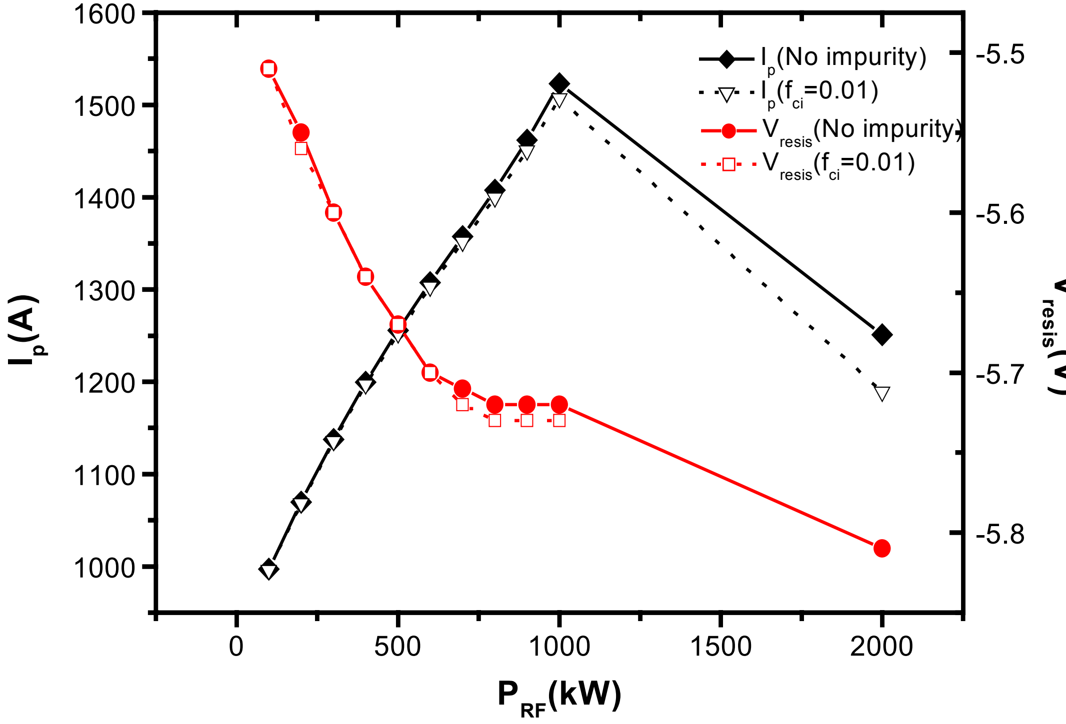


FIG. 4-1. (b) The plasma current I_p and resistive voltage V_{resis} at 60 ms, plotted as a function of the RF power P_{RF}.

Fundamental harmonic case

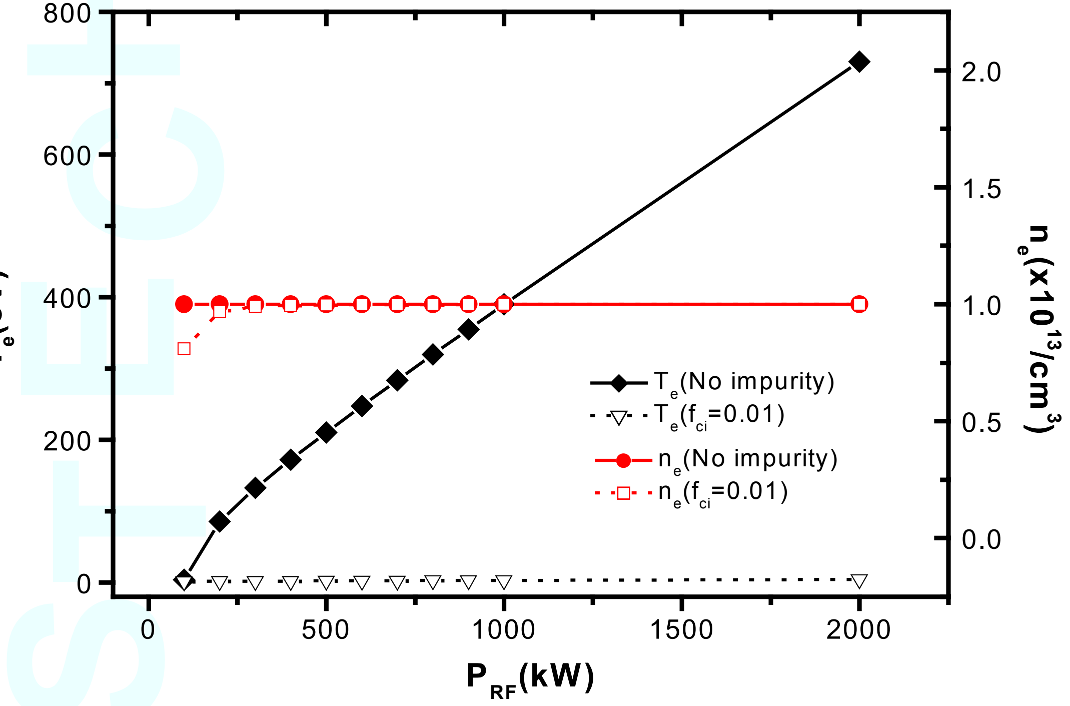


FIG. 4-2. (a) The electron temperature T_e and electron density n_e at 60 ms, plotted as a function of the RF power $P_{RF.}$

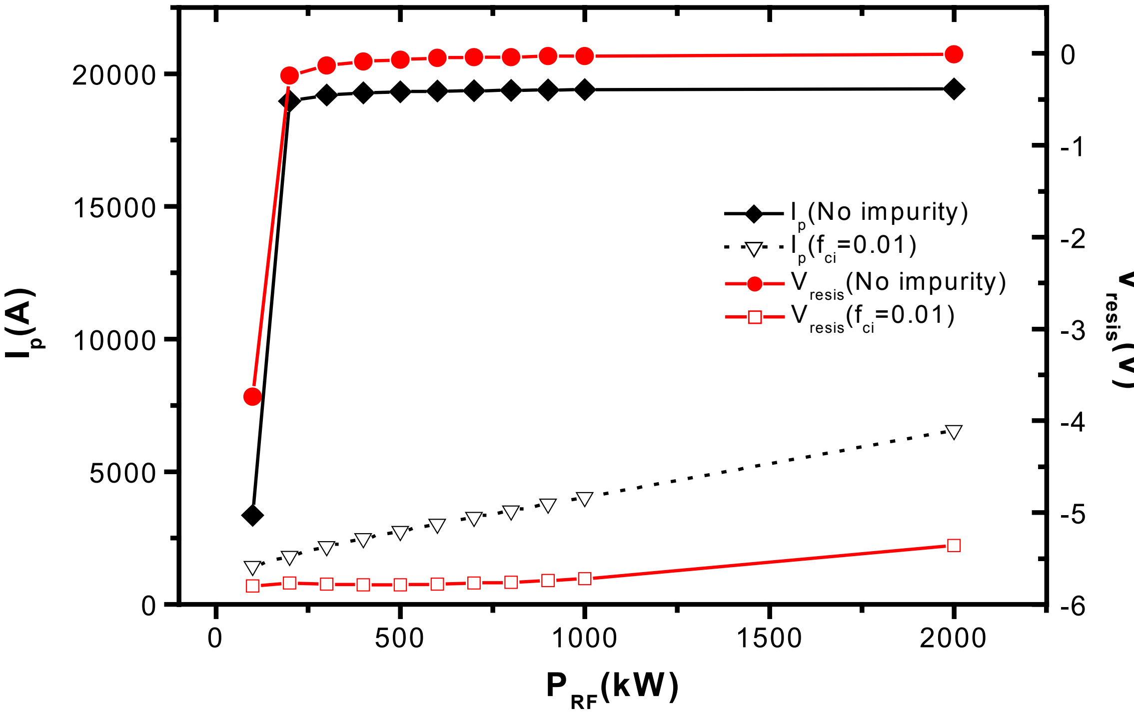


FIG. 4-2. (b) The plasma current I_p and resistive voltage V_{resis} at 60 ms, plotted as a function of the RF power P_{RF}.

Conclusion

1. For the second harmonic case, ECH pre-ionization is not effective for initiating plasma. To make plasma initially, we must modify the central magnetic field to make fundamental harmonic magnetic field (3T) in tokamak or use mode conversion. For the fundamental harmonic case, ECH pre-ionization is very outstanding effect.
2. For the second harmonic ECH heating, the impurity effects are not significant and T_e and I_p maximized near 500 ~ 1000 kW RF power.

References

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3. Y-K. M. Peng, et al., Nuclear Fusion **18**, 1489 (1978)