Electron energy distribution functions modified by MacKenzie Maxwell Demons

Noah Hershkowitz and Chi-Shung Yip

University of Wisconsin – Madison

GEC, Salt Lake City, UT, November 14, 2011
What is a Maxwell demon?

- The classical Maxwell demon is an imagined technique that raises the temperature of a gas by intelligently allowing the escape of cold molecules through trap door
- MacKenzie et al. heated plasma electrons by an angular momentum trap of cold electrons with a 60 x 60 cm grid of 0.03mm tungsten wire (400 of them) in a 1-m diameter by 2-m long filament discharge chamber [1]
- Hot electrons orbit the wires and return to the plasma. Cold electrons are absorbed
- He named his device “Maxwell Demon”
- MacKenzie also observed an instability associated with the demon when the applied voltage was high. However, such instability was not studied since then

MacKenzie’s Maxwell demon increases both $T_e$ and $V_p$.

FIG. 1. Grid current ($I$), plasma potential ($V_p$), and electron temperature ($T_e$) vs grid potential.
Our experiments were carried out in a multi-dipole device.
Experimental Procedures

• Plasma electron temperatures are measured by a disk Langmuir probe and fit to a bi-Maxwellian distribution.

• An effective temperature is determined by the average of the inverse temperature of the two electron species. The effective temperature determines the ion acoustic wave velocity.

• Plasma potentials during the instability measured by a floating emissive probe.

There are 4 species of electrons

- Energetic “primary” electrons emitted from hot negatively biased filaments
- Cold electrons from ionization by primary electrons
- Other cold electrons from ionization by the tail of the Maxwellian
- Warm electrons from secondary electron emission by primary electrons at the walls
Planar Langmuir probe shows bi-Maxwellian

Cold part is determined by subtracting the warm electrons extrapolated into plasma potential from the Cold + Warm part.
Two varieties of demons were investigated

Unarranged

Ceramic insulated stainless steel shaft

0.025mm diam. Tungsten wires

Equally spaced

25 cm 75 wires

5 cm

0.025mm Tungsten lined up
Demon works independent of geometry

Unarranged

Equally spaced
How the Demon works:
Demon works primarily by heating up cold electrons.
Demon also increases the population of the warm electrons.
Plate electrode raises plasma potential but does not always heat the plasma.
Dominant electrode not a good way to raise $T_e$
Dominant electrode and demon together don’t increase ultimate temperature rise

Electron Temperature (eV)

Applied Demon Voltage

- Plate 0V Argon 700uTorr
- Plate 20V Argon 700uTorr
- Plate 0V Xenon 200uTorr
- Plate 20V Xenon 200uTorr
Maxwell demon instability – when the demon doesn’t work

Anode Spot
Observations

• Geometrically dependent: not all shapes show equal potential to produce the instability

• Anode spots are sometimes observed when instability is present

• Instabilities are not always regular, but they are usually a mix of simultaneous occurrences of anode spots in different locations on the demon
It makes more sense to look at the dependence on Debye length.
Partial explanation of the instabilities

- Demon serves as an electrode with variable effective area $A_{\text{eff}}$
- Increasing $V_{\text{demon}}$ increases $T_e$ and Debye length
- As Debye length increases, $A_{\text{eff}}$ increases
- Increased $V_{\text{demon}} - V_{\text{plasma}}$ increases $A_{\text{eff}}$
- Anode spot forms when $A_{\text{eff}} / A_{\text{chamber}} < (m_e/m_i)^{1/2}$ and $V_{\text{demon}}$ is at least one ionization energy greater than $V_{\text{plasma}}$ [2]
- Jump in $V_{\text{plasma}}$ increases plasma density and reduces Debye length

Frequency and plasma potential when instability is turned on increases with demon potential.

![Graph showing the relationship between plasma potential and demon voltage, with two lines representing 3mTorr and 2.1mTorr, and another graph showing the instability frequency vs demon voltage in 1.4mTorr Argon plasma.](image)
Increasing the plasma density (by filament emission) raises the threshold of instability occurrence.
Summary

• The Maxwell demon has been revisited and found to work as MacKenzie et al. even though the new demons lack the geometrical feature of the original design.

• Two Mechanisms for heating: 1. increasing warm electron population and 2. heating the cold population in a bi-Maxwellian velocity distribution function.

• Demon instability was investigated - its nature better established – associated anode spots were identified.
This work was supported by U.S. Department of Energy Grants No. DE-FG02-97ER54437 and No. DE-FG02-03ER54728, National Science Foundation Grants No. CBET-0903832, and No. CBET-0903783