9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

The frequency limits of plasma response to pulsed ion acoustic wave excitation in a multi-dipole confined hot cathode discharge

Chenyao Jin[1], Chi-Shung Yip[1], Wei Zhang[1], Di Jiang[1], Jiangang Li[1]

[1] Institute of Plasma Physics, Hefei Institute of Physical Science, Chinese Academy of Science

e-mail (speaker): chenyao.jin@ipp.ac.cn

Ion Acoustic Waves (IAWs) are among the most common propagating waves in low-temperature plasmas and have been extensively studied. However, an intriguing aspect of IAWs remains unexplored: the frequency limit of plasma response to a pulsed excited IAW. This phenomenon has been observed sporadically in various laboratory plasma experiments involving IAW pulses.

Figure 1 illustrates the obtained IAW response at various plasmas. This presentation reports the discovery of a frequency limit at approximately 1/140 of the ion plasma frequency f_{pi} in the plasma's ion acoustic response to excitation waves, regardless of differing plasma parameters, excitation waveforms, and neutral pressures. This limiting response frequency is significantly lower than the expected ion acoustic resonance frequency of the plasma, which previous computational and experimental studies have shown to be greater than $f_{pi}/10$[1-3]. The corresponding wavelength, approximately 860 times the Debye length λ_{Debye}, also does not match the plasma resonance wavelengths, device dimensions, or grid dimensions.

The results indicate that the preferred plasma response to an excitation pulse may not reflect its wave resonance characteristics, and other effects related to plasma parameters may be influencing the response. Experiments also reveal an inverse relationship between plasma density and excited wave amplitude under identical excitation conditions, as well as a strong inverse correlation between the amplitude of the excited wave and the expected sheath thickness near the launch grid. This suggests that the fundamental process of exciting ion acoustic waves mirrors that of capacitively coupled plasma heating through sheath fluctuations.

These findings have implications for other wave-related plasmas, such as pulsed RF plasmas, indicating that pulsed RF power may have unintended effects on plasma uniformity. This is because the same dynamics might drive both electrons and ions, with electrons responding to the driving frequency, while ions may potentially respond to the Fourier component of the pulsed RF voltage at its limiting response frequency. Further studies are warranted to investigate how the limiting frequency is determined and whether pulsed IAWs are indeed significantly driven in pulsed RF plasmas. This work is supported by the National Natural Science Foundation of China (Grant Nos. 12275305 and 12205334), the Postdoctoral Fellowship Program of CPSF (Grant No. GZB20240755), China Postdoctoral Science Foundation (Grant No. 2024M763308)

References

[1] Baalrud S D et al 2011 Plasma Sources Sci. Technol. 20 025013

[2] Baalrud S D et al 2009 Phys. Rev. Lett. 102 245005

[3] Jiang D et al 2024 J. Appl. Phys. 57 095202

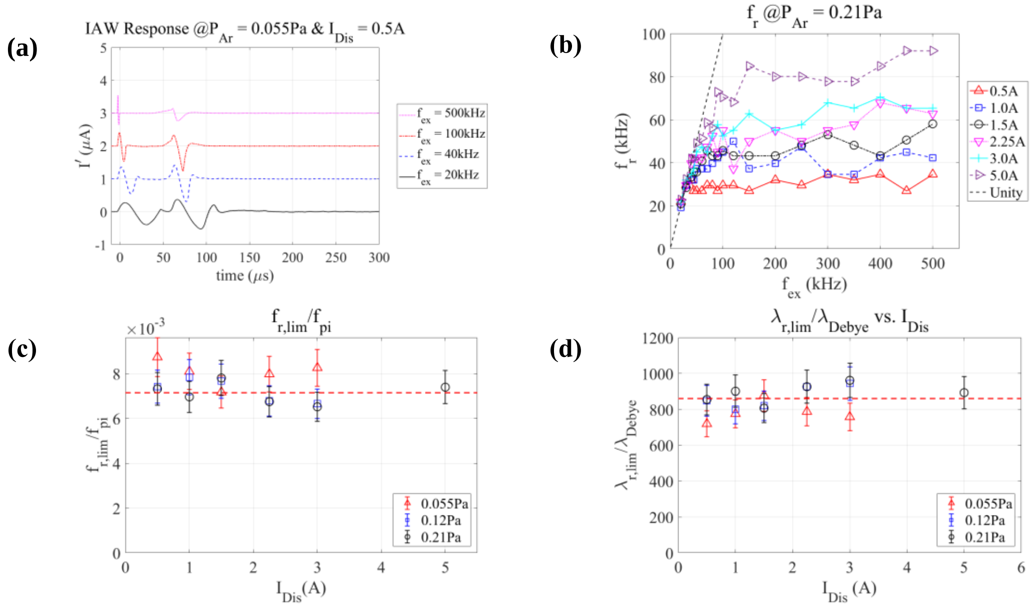

Figure 1. (a) IAW signal obtained from the Langmuir probe, (b) Plasma's IAW response frequency f_r graphed versus the grid excitation frequency f_{ex} at various I_{Dis}. (c) Limiting frequency and (d) limiting wavelength of the plasma's IAW response, normalized against the ion plasma frequency and Debye length, respectively, graphed against the discharge current I_{Dis} at various neutral pressure P_{Ar}. Dashed red line indicates $f_{r,lim}/f_{pi} = 1/140$ and $\lambda_{r,lim}/\lambda_{Debye} = 860$.