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

Investigation of discharge characteristics of high-energy microwave plasma switches with different electrode spacings

Jingfeng Yao[1,2], Zijian Liu[1], Zijia Chu[1], Jianfei Li[1], Chengxun Yuan[1,2]
[1] School of Physics, Harbin Institute of Technology, China, [2] Heilongjiang Provincial Key Laboratory of Plasma Physics and Application Technology, China
e-mail (speaker): yaohit@163.com

Microwave plasma switch is a device that utilizes the metallic-like properties of high-density plasma to reflect and block microwaves. It is applied in active microwave pulse compressors and for protecting microwave devices[1]. The discharge characteristics of the plasma switch need to be studied in order to guide its design and optimization. Due to the extremely short duration of the activation period, which is only on the order of nanoseconds, the measurement methods for the discharge characteristics are severely limited. We established a three-dimensional model of a microwave plasma switch triggered by needle-shaped high-voltage electrodes, and used fluid models to simulate the process of plasma generation[2].

This report investigates the discharge characteristics of microwave plasma switches at different electrode spacings. A three-dimensional self-consistent microwave plasma model is proposed to describe the plasma evolution from excitation to full closure of the plasma switch at high energy microwaves. An experimental setup for a plasma switch operating in a travelling wave field was subsequently built. The incident microwave frequency was S-band, the microwave incident power was 10 kW, the air pressure of the plasma switch was 50 Torr, and the plasma switch electrode voltage was 8 kV. We measured the reflection and transmission coefficients of microwaves during the discharge process of the plasma switch. The simulation results show that the excitation in microwave plasma can be divided into two different phases, which are the spark discharge phase dominated by flow injection and the microwave heating phase. During the spark discharge phase, an initial plasma is generated that concentrates a radio frequency (RF) electric field on the upper and lower ends of the plasma region. The plasma then expands under electromagnetic wave heating until the electromagnetic wave is reflected outside the gas discharge tube (GDT) due to the skin effect. The response speed of the plasma switch is on the order of a hundred nanoseconds for small electrode spacings and tens of nanoseconds for large electrode spacings. The trend of experimental measurements coincided with the simulation results, which verified the accuracy of the simulation results.

The simulation results show that the smaller the electrode spacing, the earlier the occurrence of spark discharge between the electrodes, and the higher the spark discharge current and the electron density between the electrodes. When the electrode spacing is relatively small, the reflection coefficient and response speed of the plasma switch will decrease because the plasma cannot effectively reflect electromagnetic waves, and the expansion speed of the plasma region is also slower. It is worth noting that the simulation results indicate that the plasma switch performs best when the maximum electrode spacing is 30 millimeters. Studying the plasma dynamics within the plasma switch helps to gain a deeper understanding of the generation and expansion process of plasma, which will assist us in designing and optimizing plasma switch tubes in the future and constructing microwave pulse compression systems with higher cavity gain and better output waveforms.

References

[1] S.N. Artemenko, V.S. Igumnov, A.S. Shlapakovsky, and Y.G. Yushkov, IEEE Trans. Microwave Theory Tech., vol. 67, no. 2, pp. 597–605, Jan. 2019.
[2] Z. Liu, V. S. Igumnov, Z. Chu, J. Li, Y. Wang, Z. Zhou, C. Yuan, and J. Yao, IEEE Trans. Microw. Theory Tech., Jan. 2025.

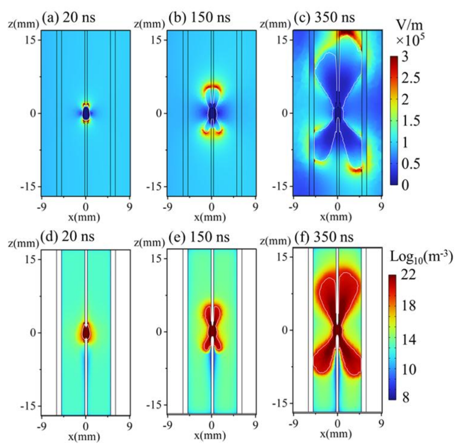

Figure 1 Electrode distance is 2 mm. (a)–(c) Microwave electric field norm distribution (V/m) in the GDT. (d)–(f) Electron density distribution (m–3) at different times.