Instability in Nonequilibrium and Nonthermal Plasma Discharges

Abstract

Microplasma, or plasma in micron scale interelectrode separation, is an effective way to attain nonthermal plasma operation at atmospheric and higher pressure. However, the small size causes the effect of other operating parameters to be crucial in stable operation and make the microplasma discharge system to be susceptible to instabilities. The two major instabilities that are commonly observed are the instability in the negative differential resistance (NDR) region and the Striations or the ionization waves. The physics and reaction kinetics of NDR instability for high pressure system is not well understood. This study pursues both experimental characterization and development of mathematical models to understand the physicochemical processes of direct current driven self pulsing non-thermal plasma discharge. The second category of instability that is observed in microplasma discharges is striations, which was previously found in the low pressure discharges. Striations in the positive column is a major efficiency barrier for many potential applications in microplasma discharge system. However, even though there are several investigations, a consistent theoretical framework for describing this phenomenon, especially for diatomic gases, is absent. For this purpose, we propose a detailed mathematical model that considers elaborate vibrational kinetics that is associated with diatomic gases and has shown that for diatomic gases the energy cascades from electrons to vibrational excited states, contributing to the striation formation. A low pressure discharge system was considered for the Striaions modeling due to the availability of experimental data in such conditions.

One of the important applications of plasma discharge is the application in plasma enhanced chemical vapor deposition and micro patterning where the smallest feature size is

dictated by the smallest discharge current at which stable discharge can be attained. There are no existing method that is aimed at suppressing the instability of atmospheric and high pressure. In this study, a mathematical model was developed to suppress the NDR instability through an external circuit. The mathematical model was validated experimentally and found that the instability in the NDR region can be modulated and suppressed using an external circuit element.

Although microplasma offers significant technical benefits, the small size of the system makes it extremely difficult to perform diagnostics and ion detection. In addition, traditional OES, Laser or other spectroscopic measurements are challenging due to the high collisionality of microplasma discharge at elevated pressure. In this study, a mathematical model is proposed to predict the ion number density in the microplasma discharges based on the readily available relaxation frequency in the NDR region. The model was validated experimentally and found to be in a good quantitative agreement with the multiphysics numerical model.