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Peering inside microplasmas sustained by microwaves, millimeter waves and beyond[1]

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Atmospheric microplasmas are experimentally investigated over a range of excitation frequency from 0.5 to 12 GHz. A validated fluid model correctly predicts the measured electron density in this band of operation. This model is then extended to predict plasma behavior up to 0.4 THz. At constant power (0.25 W), the central electron density increases to $5x10^{14}$ cm^{-3} as the microwave frequency increases toward the electron energy dissipation frequency of 5 GHz (in argon). Above 5 GHz, the argon plasma density remains approximately constant, but the electrode voltage decreases to less than 5 volts in amplitude. This is remarkable in that the microwave potential is less than the excitation potential of argon. In the millimeter wave band, we observe series resonance between the plasma inductance and sheath capacitance at ˜30 GHz. The parallel resonance results in strong electron oscillation within the microplasma at the position where the electron plasma frequency is equal to the excitation frequency (˜200 GHz). Crossing resonance boundaries changes the nature of the microplasma impedance between capacitive, resistive, and inductive. In addition to linear behavior, we also present models and measurements of microplasma nonlinearity. Nonlinearity generates harmonic plasma currents and is due primarily to dynamic sheath expansion and electron conduction currents. In total, the microplasma provides a rich variety of electromagnetic behaviors that can be incorporated into plasma-reconfigurable metamaterials and photonic crystals.

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