Metasurface based micro-plasma device

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Abstract-A metasurface based micro-plasma device is proposed taking advantage of the inherent resonance of the surface. The structure combines the DC and laser induced discharges and reduces both the required DC voltage and laser power to ignite the plasma.

Plasma devices offer several benefits compared to their counterparts using semiconductors as the conducting channel. The self-healing property of plasma makes it more resilient to environmental conditions including overvoltage and radiation. In addition, gas plasma is potentially faster and capable of handling higher powers. Due to the fact that performance of plasma devices is mainly characterized by parameters such as air pressure and geometry, they can be flexibly used in a broad range of applications. However, plasmas are susceptible to instabilities, in particular arcing. One approach to sustaining stable plasma in atmospheric pressures is confining the dimensions to below 1mm cavities to lie within a certain range of pressure-distance product. There has been extensive interest in the spatially confined micro-plasma devices; however, there are several challenges including ignition and confinement of plasma, and packaging of the devices.

![Figure 1](image)

Figure 1. Proposed structure: a) unit-cell, b) unit-cell top view, air gap width, air gap length, finger width, and finger length are 100, 125, 300, and 500 nm, c) periodic array, d) periodic array side view, air gap height, top metal layer height, and bottom metal layer height are 200, 200, 100 nm.

The proposed metasurface based micro-plasma device integrates the benefits of micro-plasma with the combination of DC and laser induced discharges using the electromagnetic resonance. The key element of the metasurface based device is the enhancement of electric field due to the resonance which increases the interaction of the wave with matter. A similar phenomenon occurs in surface-enhanced Raman scattering where the fissures in the rough surface act as high Q optical cavities. The inherent resonance frequency of the designed periodic structure depends on the geometry. The metasurface is DC biased at a much lower voltage than
conventional micro-plasma devices and excited by a low-power optical field corresponding to the resonance frequency of the surface. The combination of the laser-induced and DC breakdown, reduces both the required voltage and laser power to ignite the plasma. Furthermore, due to the coupling between the unit-cells sharing the same gas, the plasma may spread over the surface making the device scalable to higher powers.

Figure 1(a) shows a unit-cell of the proposed structure. The surface consists of metallic air-bridges, supported by anchors on the sides, on a thin layer of air. The substrate below the periodic bridges is isolated from the top layer by a thin metallic plane covering the area between the anchors across the whole array. Figure 1(d) shows the side view of different layers in a 10x6 array. The geometry is designed such that the maximum field enhancement due to resonance at a certain frequency occurs in the air gap between fingers on two adjacent bridges as shown in figure 2. There are various options available for controlling the plasma-surface interaction by using different field profiles associated with different resonances.

![Figure 2](image)

Figure 2. Field profiles at resonance frequencies: a) 343.5 THz, b) 355.25 THz, c) Reflection phase VS. frequency, resonances at 343.5 and 355.2 THz.

Fabrication of air-bridges is done using multiple dose electron-beam lithography. The exposure is done in a single step using the same acceleration voltage and applying different dosages on the bridge span and feet areas. The process can be done using multiple-layer resists in order to facilitate lift-off. The desired air-bridge profile is obtained by setting the beam voltage such that the penetration depth is smaller than the resist thickness, and controlling the height of the air-gap underneath the bridge by applying a lower electron dosage in the span area than the anchors. An adhesion layer of Ti and the top Au layer are then evaporated on the developed sample.

The resonance behavior is measured using reflection spectroscopy. Average reflections from uniform silicon and gold surfaces are used to normalize the reflections measured from the fabricated metasurface. The measurement setup consists of a fiber coupled broadband light source connected to a parabolic reflector collimator, a polarized beam splitter, an objective lens (NA=0.55), a camera with its lens system, and a spectrometer. The final version of the metasurface to be measured is still in the fabrication process.

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REFERENCES