Split-Post Dielectric Resonator Plasma Generators

Zane Cohick[1], Wei Luo[1], Jeffrey Hopwood[2], Douglas Wolfe[1], and Michael Lanagan[1]
[1] Pennsylvania State University, State College, PA, [2] Tufts University, Medford, MA

Introduction

Metamaterials have become popular among the public in recent years due to some fascinating possibilities. These possibilities include invisibility cloaks, perfect lenses, and perfect absorbers that rely on properties such as negative refractive index, which can be achieved with metamaterials[1-3].

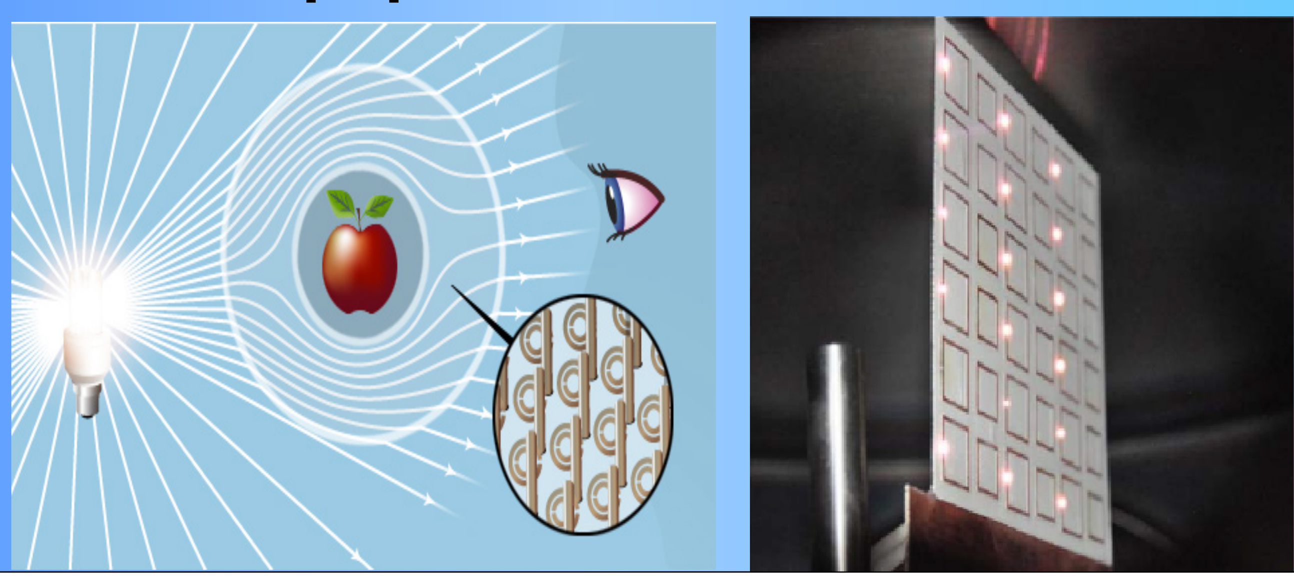

Figure 1*: An illustration of an invisibility cloak (left)[8]. On the right an array of ring resonators of two different sizes with gaps of ~160µm are shown. The resonators are subject to radiation from a patch antenna at 2.41GHz. The result, as seen above, is plasma generation in the large rings' gaps [4].*

One of the limitations of metamaterials that researchers have been trying to overcome is the narrow bandwidth in which they often function. By replacing the traditional metal components of metamaterials with plasmas it may be possible to rapidly tune metamaterials to work at many frequencies from GHz to THz range. This tunability arises because plasma properties can be controlled via parameters such as input power and pressure [5,6]. Recently, arrays of plasmas, which may be used in plasma metamaterials/photonic crystals, were generated using split-ring resonators (SRRs) [7]. The SRR is a common metamaterial unit cell and its use in plasma array generation is shown in Figure 1. This may be thought of as a metamaterial used to generate another metamaterial.

Goals

- Reduce energy losses due to high-frequency (GHz-THz) wave interactions with metals
- Remotely ignite plasmas using excitation of dielectric resonators
- Reduce the power required to generate microplasma arrays
- Find materials that can withstand plasma damage while also optimizing plasma generation properties

Dielectric Resonators

•Dielectric Resonators store electromagnetic energy that can be utilized for plasma generation

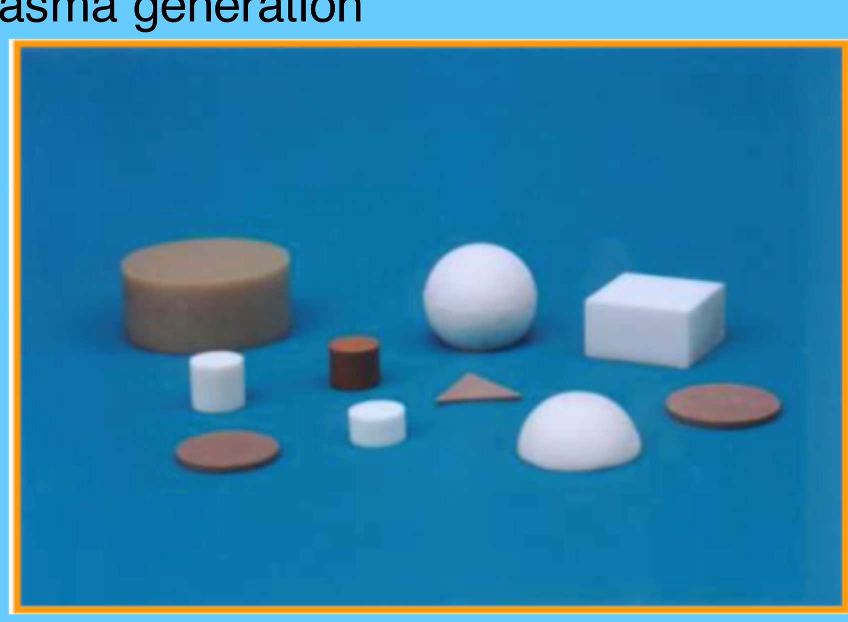

Figure 2: Dielectric resonators can be fabricated in a variety of different shapes and sizes in order to control properties such as resonant frequency and electromagnetic field patterns [9].

Electrical Characterization and Simulation

•Cylindrical dielectric resonators composed of $Zr_{0.8}Sn_{0.2}TiO_4$ (ZST) were halved as shown in Figure 3 and their properties were studied

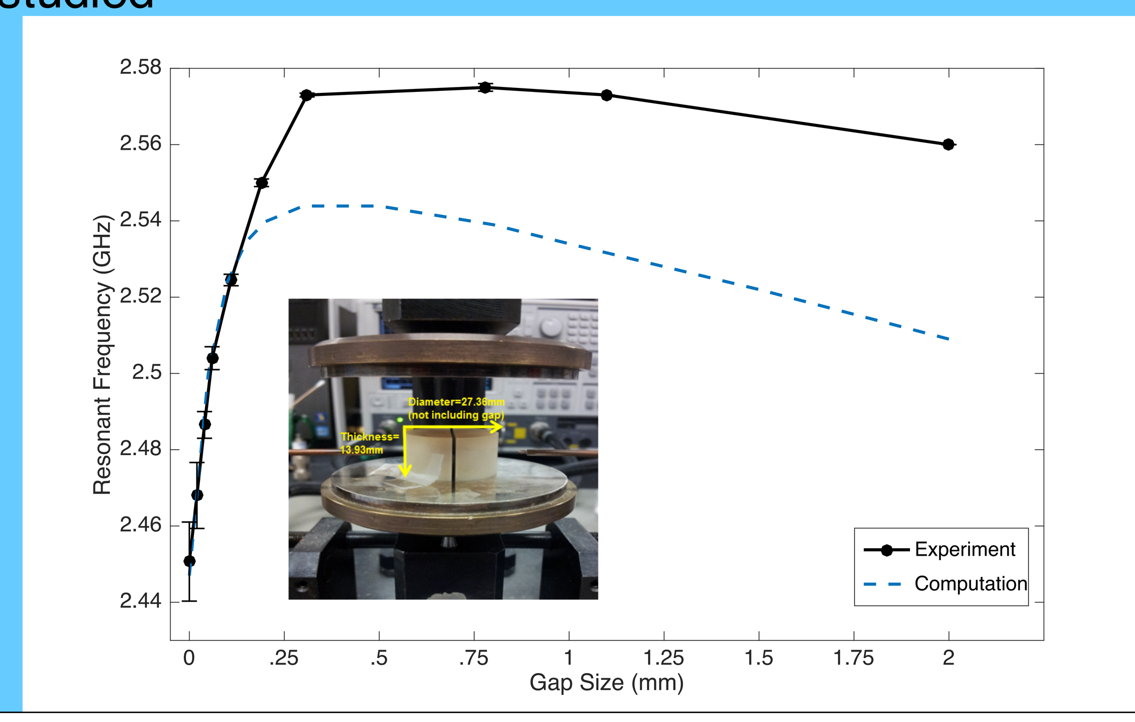

Figure 3: *Resonant frequency of the TE011 mode is shown as a function of the gap distance between the two halves of the resonator. In the inset, a Hakki-Coleman setup for studying dielectric properties is shown with the ZST resonator.*

•Figure 3 shows that the resonant frequency increases rapidly at first and then the slope changes. This is an indication of new electromagnetic modes being excited

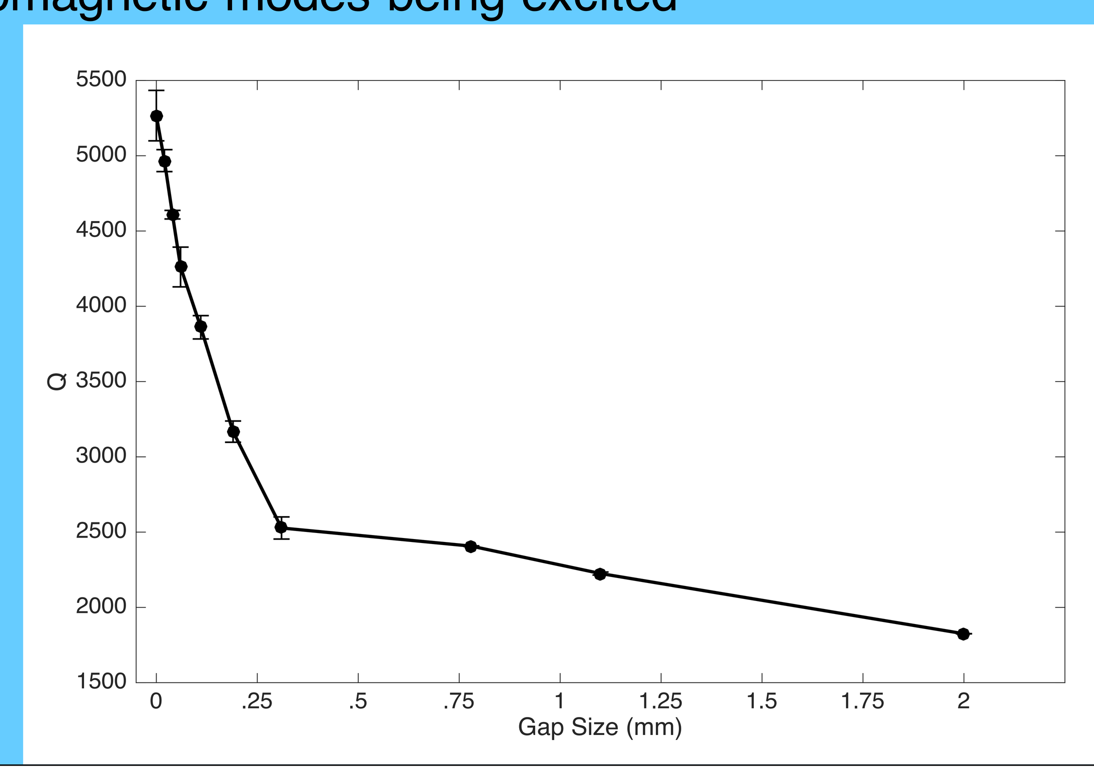

Figure 4: *Quality factor of the resonator versus the gap distance.*

•The quality factor (Q) of dielectrics can be orders of magnitude higher than split-ring resonators. Q is seen to decrease rapidly at first and then the slope changes. This may indicate a change in the electromagnetic mode being excited.

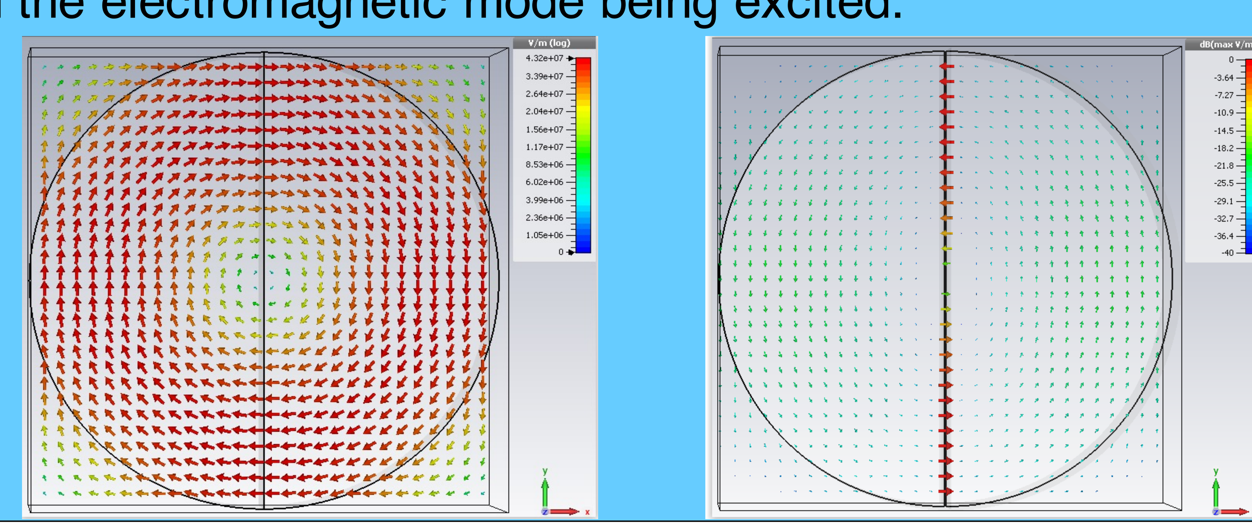

Figure 5: *Simulations showing electric-field distributions of TE011 mode in a dielectric resonator (left) and the field distribution of the same mode in a split resonator. Note: Scales for electric fields are different for each image.*

•The electric field in the gap is about 40x higher than inside the resonator adjacent to the gap. This corresponds to ZST's permittivity (~37).

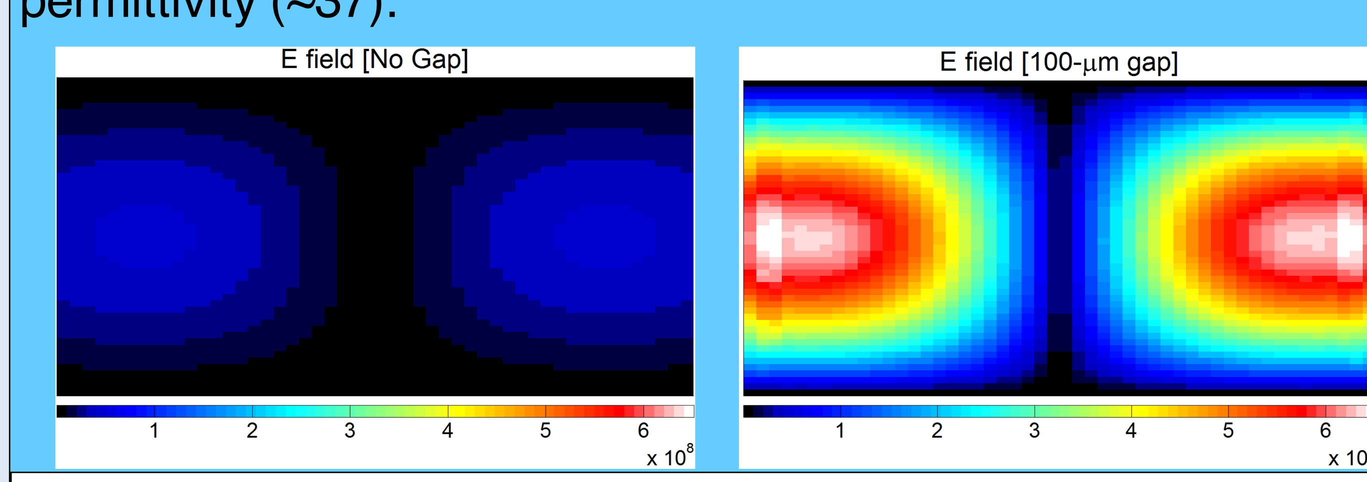

Figure 6: *Simulations showing electric-field magnitude (V/m) in a split (right) and non-split dielectric resonator. These cross sections correspond to the center of the resonator parallel to the split.*

Plasma Generation

Figure 7: *Plasma generation in atmosphere is visible in dielectrics subject to 1000W of multimode microwaves at 2.45GHz. On the left is a $Zr_{0.8}Sn_{0.2}TiO_4$ resonator and on the right are two identical $CaTiO_3$ resonators designed to resonate in TE011 and HEM12δ modes respectively when excited by 2.45GHz microwaves.*
Thanks to Jipeng Cheng and Dinesh Agrawal for assisting with the plasma experiments.

•1000W using multimode excitation was required to generate plasma at atmospheric pressure.

•Simulations show similar power requirements. The same simulation predicts that 1W of power can ignite a plasma in 1Torr of Ar.

Future Work

•Thin-films (~1um) of titanium carbide (TiC) are deposited via e-beam onto the dielectric surface (Figure 7) in order to act as a source of electrons for plasma generation and sustenance.

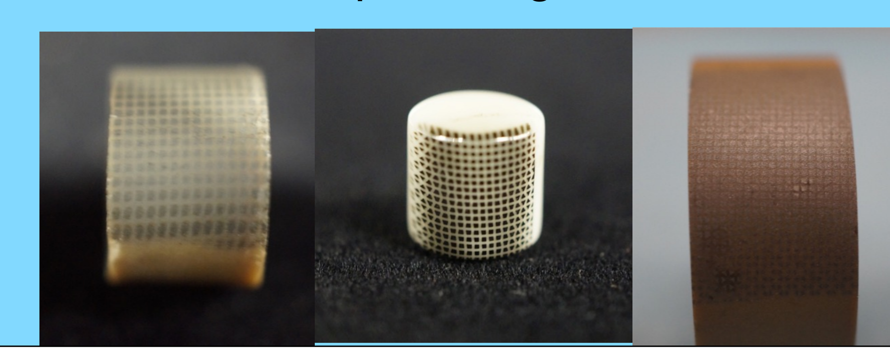

Figure 8: *Thin films of TiC deposited via E-beam deposition on dielectric resonators. The fishnet pattern of the films (300umx300um squares) helps the dielectrics to retain their high Q (4x higher than continuous film) while offering a source of free-electrons.*

Summary

•Frequency and Q-factor of halved-ZST resonators vary as a function of gap distance and suggest the existence of mode splitting beyond 0.5mm gap sizes.

•Simulations of halved-dielectric resonators show promise for electric field enhancement.

•Halved-dielectric resonators have been successfully used to generate plasma with powers in agreement with simulated results.

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