P1-25: CW Microwave Radiation Source from Micro-Hollow Cathode Plasma Discharge

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Abstract: *A continuous-wave microwave radiation source is under investigation using Micro-Hollow Cathode Discharge (MHCD) technology. Arrays of grooves, 50 microns in diameter and ~3 mm long have been fabricated to contain the plasma discharge. Argon discharge in the resonance cavity has been observed at atmospheric pressure. The turn-on voltage was observed to be 400V (383μA). Lowering the voltage to 310V (~100μA) extinguished the plasma. Increasing the applied voltage to 400V (430μA), a broad-spectrum radiation with center frequency at 131MHz was measured.*

Keywords: micro-hollow cathode discharge; MHCD; microwave; terahertz radiation; plasma discharge.

Introduction

High power microwave sources are very useful for many commercial and military applications. Specifically, the sub-millimeter-wave regime between 1mm (300 GHz) and 100μm (3 THz) offers several technical advantages, such as wider bandwidth, improved spatial resolution, and component compactness [1]. Despite increased interest and discoveries in field of THz radiation, there are still many scientific and technical challenges to overcome, such as, the development of a high power solid-state continuous-wave THz radiation source [1].

The use of plasmas as a radiating source was first explored by Tonks in 1932 [2]. More recently, Borg has explored the use of plasmas as microwave radiation elements [3] and Golubev et al. have proposed a terahertz generator based on using a laser spark plasma in a static electric field [4]. In this study, we propose and demonstrate a high frequency radiation source based on using a Micro-Hollow Cathode Discharge (MHCD) as the plasma generator.

MHCD plasma sources produce discharges between a cathode, which has a hollow structure, and an arbitrarily shaped anode [5]. The structure of the cathode can be of any size, but in order to operate the device at atmospheric pressure or higher, the width of these cavities must be in the micrometer range. Consequently, cavities with such dimensions have electromagnetic resonances in the microwave to the terahertz range. This suggests that a plasma discharge in a micrometer-sized can potentially be used as microwave radiation source.

The plasma has an effective dielectric constant less than unity, depending on the density of free electrons, according to

$$\frac{\varepsilon(\omega)}{\varepsilon_0} = 1 - \frac{n_e e^2}{\varepsilon_0 \omega^2 m}$$

where ε_0 is the permittivity of vacuum, n_e is the electron density, ω is the radian frequency and e and m are the charge and mass of an electron. The plasma resonant frequency, f_p, occurs when $\varepsilon(\omega) = 0$,

$$f_p = 8.98x10^3 (n_e)^{1/2}$$

In order for this to be in the microwave range, (1 GHz$\leq f_p \leq$100GHz) we must have $10^{10} \leq n_e \leq 10^{14}$ cm^{-3}. Borg et al. has shown that plasma can be used as a radiative source [3]. By using microfabrication technology, large arrays of high density MHCD structures can fabricated to provide a high power, high frequency radiation source. For terahertz frequencies the plasma density must be increased to $10^{10} \leq n_e \leq 10^{17}$ cm^{-3}.

Experimental Setup

Arrays of Micro-Hollow Cathode grooves were fabricated for our experiments (Figure 1). A long stainless-steel tube with inner and outer diameter of 50um and 150um, respectively, was tightly wrapped around a piece of aluminum substrate. Epoxy was then applied over the tightly packed tubing and cured. The stainless steel tubes were then polished, exposing the inner diameter of the tube. The device was inspected and the dimensions were measured under a microscope. The final experimental devices were cleaned with methanol and isopropanol.
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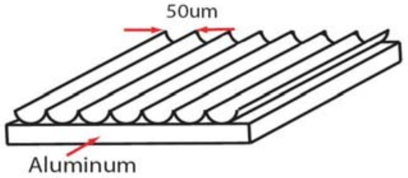

Figure 1. Schematic of an array of MHCD grooves.

The finished device was mounted under a microscope. The aluminum substrate was grounded. At atmospheric pressure, a low flow of Ar was directed over the microgrooves. A micro-manipulator was used to precisely position the anode above one end of the groove. A probe tip in series with a 490kΩ resistor was used as the anode, and was connected to a positive voltage supply. With a small voltage applied to the anode, the anode was lowered to make contact with the cathode until a current was observed. The anode was then raised just enough to create an open circuit. With the Ar flowing, the voltage was slowly increased until a MHCD in the groove was observed. The voltage was then lowered to find the voltage where the self-sustaining discharge would extinguish.

Results and Discussion

A MHCD in Ar gas at atmospheric pressure is seen in Figure 2. The voltage and current were 510V and 500µA respectively. The confined plasma was ~275µm in length and ~14µm wide.

The length of the plasma depends greatly on the anode voltage. Increases in voltage lengthens the discharge, while decreases in voltage shortens the length of the plasma until it extinguishes at 310V and an open circuit is observed. Discharge current as high as 1.5mA was observed before the cathode material turned red and over-heated. In Figure 2, the brightest spot seen is at the location of the anode.

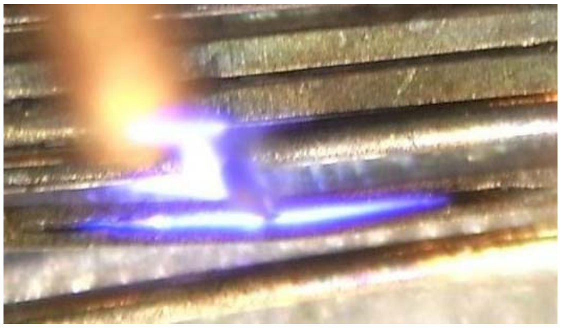

Figure 2. Picture of a MHCD with Argon gas at 800V and 1.2mA

Using a spectrum analyzer and a capacitive probe, we have seen evidence of radio frequency energy coming from the plasma. Figure 3 shows a plot of the observed power spectrum with a center frequency at 131MHz and ~20dBm gain. According to above plasma resonant frequency equation, the plasma density corresponds to $2.13x10^{8}\text{cm}^{-3}$.

Brodie et al. demonstrated a plasma density of $9x10^{12}$ cm^{-3} in Ar at atmospheric pressure in previous experiments [6], which translates to a plasma frequency of 27GHz. In order to push the plasma frequency to higher microwave frequencies, five parameters of the MHCD will be explored to maximize the plasma electron density. First, a cathode material with high secondary electron yield and high conductivity will be used to increase the electron density. Second, increasing the pressure of the system to above one atmosphere will provide a higher concentration of available neutral atoms for ionization. Third, a gas species with lower ionization energy will be explored to provide a higher plasma electron concentration at lower operating voltages. Fourth, increasing the extraction voltages translates into higher currents, which will also increase the plasma density. Lastly, the diameter of the hollow cathode can be decreased to compress the plasma into a smaller volume.

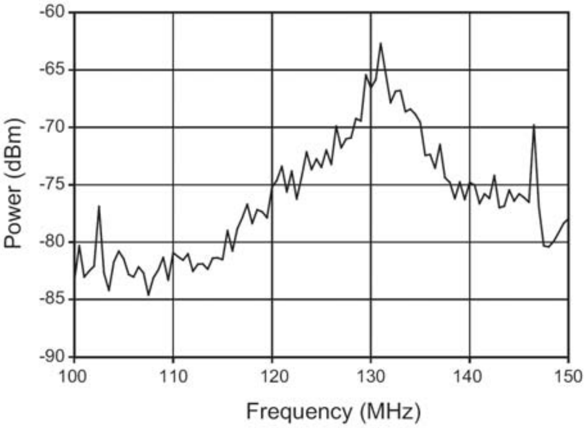

Figure 3. Plot of power spectrum measured from a MHCD with Ar gas at 400V and 430µA

Conclusion

A novel microwave radiation source is, using a MHCD is demonstrated. An array of MHCD grooves have been fabricated by polishing micro-size stainless-steel tubing until the inner diameter was exposed. MHCD was observed at operating voltages ranging from 300 to 700V in Ar gas at atmospheric pressure. Experimental verification of the characteristic frequency and radiative power produced by the source has been observed.

References

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