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Technical Support Package

Slot-Antenna/Permanent-Magnet Device for Generating Plasma

NASA Tech Briefs
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Technical Support Package

for

SLOT-ANTENNA/PERMANENT-MAGNET DEVICE FOR GENERATING PLASMA

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NASA Tech Briefs

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Slot-Antenna/Permanent-Magnet Device for Generating Plasma

Brief Abstract

A high-density plasma generated by microwave injection using a windowless slotted antenna has been demonstrated. Plasma probe measurements indicate that the source could be applicable for low-power ion thruster applications or ion implantation applications. The plasma source, which operates on the principle of electron cyclotron resonance, is completely electrodeless and therefore its operation lifetime is long, being limited only by either the microwave generator itself or charged particle extraction grids if used. The high-density plasma source can also be used to extract an electron beam. In this regard, the device can be used as a plasma cathode neutralizer for ion-source beam neutralization applications.

Section I — Description of the Problem

One drawback of existing DC ion sources is erosion, lifetime, and plasma uniformity. DC ion sources naturally eject erosion products into the discharge plasma. This is a consequence of the fact that the discharge cathode is constantly being bombarded by the discharge plasma in which it is immersed. This is an undesirable attribute from the standpoint of materials processing. DC ion sources (as well as electron sources) have limited lifetimes due to the fact that these components are constantly subjected to erosion. The cathodes that drive these sources typically over time lose their abililty to emit discharge electrons at reduced temperatures. Eventually, over time, the cathode fails. Typically, DC ion sources (ion thrusters in particular) utilize a single on-axis discharge cathode. This arrangement gives rise to peaked, non-uniform plasma density profiles at the exit plane. These non-uniform profiles give rise to non-uniform wear of the ion extraction grids, thereby leading to failure by structural degradation or by electron backstreaming.

Disk-shaped multi-slotted antenna designs have been used in the past to circumvent issues described above. These sources, however, require an insulating window for operation (impedance matching and shielding). The insulating window, typically BN, makes such devices impractical for ion source or ion thruster applications because the insulating window will coat over time due to wear of the extraction grids. The coating will ultimately prevent microwaves from penetrating the source and thus plasma production will cease.

Section II — Technical Description

The purpose of the slotted antenna source is to electrodelessly generate a very uniform discharge plasma at reduced input powers and gas flow rates. The slotted antenna plasma source solves the problem of plasma generator for the ion source as well as plasma generator for the electron source. It does so in a complete electrodeless manner using electron cyclotron resonance. The slotted antenna device features a series of matched radiating slot pairs that are distributed along the length of the plasma source discharge chamber. This arrangement allows the plasma production to take place in a distributed fashion thereby giving rise to a uniform plasma profile. A uniform plasma profile is necessary for ion (electron) extraction optics uniformity. The slotted antenna design makes the approach scalable to much higher powers. All that is required is additional matched radiating slots along the length of the discharge chamber. In order for the power/slot to remain constant, input microwave power must increase accordingly. Another key attribute of the slotted antenna approach described here is that it is designed so that an insulating window is not necessary. This allows the slotted antenna source to be used for ion beam and electron beam applications. The source is designed so that ECR takes place above each slot and the magnetic field at each slot provides a strong gradient to prevent plasma's backflow. The windowless nature of this sources gives it a distinct advantage over other slotted plasma source geometries, which can only be used in non-ion beam, non-deposition type plasma applications.

Section III — Unique or Novel Features

A. Novel features:

- The source produces a distributed, uniform plasmas density profile.
- The source is operated using permanent magnets only.
- The source is capable of operating at low flow rates and low background pressures.
- The source can be used as either an electron or an ion source.
- Plasma current densities produced at the exit plane of the device are fairly large.
- The design does not require a microwave window.

B. Advantages of innovation

- The slotted antenna approach makes it straightforward to scale the device up to larger areas and higher powers.
- The high uniformity makes it applicable for plasma processing applications.
- Operation at low pressure $<10^{-4}$Torr is idea for plasma processing.
- No electromagnets are required.
- High exit plane ion current densities will yield desired high etch or deposition rates.
- No microwave window is required.

Unlike cylindrical devices, the rectangular slotted antenna design is straightforward to scale up in power and size with miminal modification to the magnetic circuit.

(See attachment for additional details)

In summary, this source is unique in comparison with traditional ECR ion sources in that it produces (1) high current densities and (2) uniform discharge plasma. Additioanally, it does not require cumbersome, energy-hungry electromagnets. The source has operated at 2.45 GHz but can be designed to operate at virtually any microwave frequency (915 MHz to 6 GHz is a typical practical range of operation). Additionally, it does not require a microwave window which would otherwise be a contamination source. For ion beam applications, this window could also be coated, thereby preventing microwaves from coupling into the source and producing a discharge plasma.

Section IV — Potential Commercial Applications

This technology is also applicable to the semiconductor manfacturing sector as well as the broader area of plasma processing. Because of the unique ease of scaling to larger areas, work-piece size is not a factor. The large uniform plasma produced by the above described source makes ideal for the processing of silicon wafers, implanting ions in various materials or controling the chemistry of a deposition plasma. In all cases, erosion products are virtually eliminated as the plasma production is a purely electrodeless process. Companies that either develop or utilize plasma sources for silicon wafer processing, implantation or deposition processing would likely be interested in this technology.

The plasma source could also be used for long-life ion thruster applications on commercial satellites. Additionally, satellite manufacturers may be interested in the source for satellite charge control. The slotted antenna source could also serve as a plasma contactor for these applications.

Attachment

Slide 1

Slotted Antenna Rectangular Waveguide Plasma Source

John E. Foster

NASA GRC

Slide 2

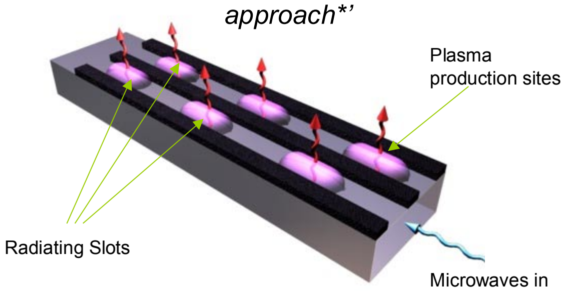
Slotted antenna source

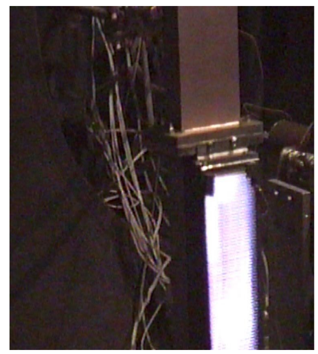
- Produces uniform discharge plasma because of distributed plasma production
- Plasma production is completely electrodeless (ECR)→no erosion products
- Utilizes all permanent magnets
- Produces high current densities
- Operates at low background pressures, low flow rates
- Straightforward to scale to high powers

Slide 3

Slotted antenna plasma source

'Slotted-Antenna approach'*



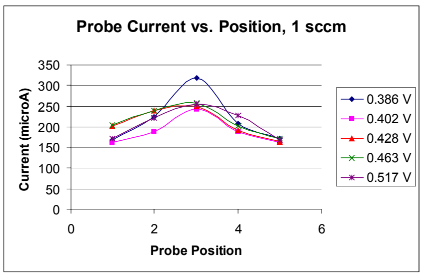


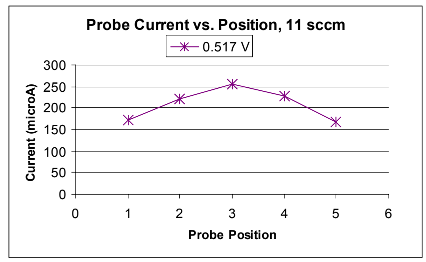
Slotted antenna source operating
(Plasma grid installed)

**graphic used in HiPEP proposal*

Slide 4

Slotted Antenna Plasma Source

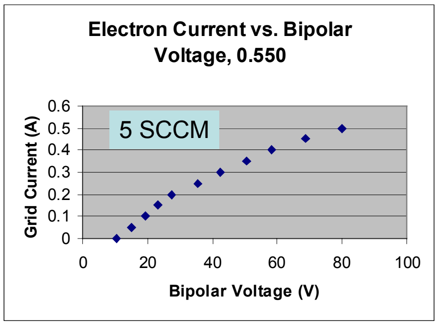


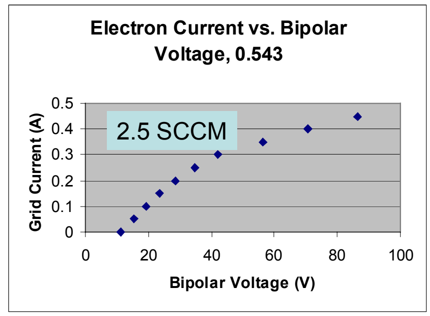


•Ion current density profiles as a function of position down the length of the rectangular plasma source at low and high flow rates between 48 and 74 W of microwave power

Slide 5

Slotted antenna plasma source





•Use of slotted antenna source as an electron source.
•Figures illustrates grid voltage as a function of extractable electron current at different flow rates

~95 W