International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 11, Issue 7 [July. 2022] PP: 32-37

Effect onPeak power, Efficiency and Frequency due to variation ininner diameter and different positionof reflectorin the Axial Vacuum Diode

Muhammad Sohail, Malik Sajjad Mehmood
Basic Sciences Department, University of Engineering & Technology, Taxila
Muhammad Sohail

ABSTRACT

A vacuum diode is a special device for generating high power microwaves. we numerically studied by using 3D-PIC simulation, CST. We varied the inner diameter of reflector and reflector's position in simulation with a voltage 420 kV. In the inner diameter of reflector case, we varied from 50mm to 80 mm and the best result of peak power i.e., 0.56 GW are coming from the 70 mm point, the highest energy efficiency 8.08% are obtaining from 65mm point.In the reflector's position variation cases the best results for peak power are 0.55 GW, when the reflector placed at position $5d_{ak}$. The highest energy efficiency 8.7% are obtained from reflector's position at $8d_{ak}$. The dominant mode of microwave emission in our cases areTM_{01}. The results generating in both cases at frequency 5 GHz.

Date of Submission: 26-06-2022 Date of Acceptance: 08-07-2022

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1. INTRODUCTION

High power microwaves have extant and virtual use in environment, Biology, Space, energy and for medical purposes. There are large number of being developed HPM sources for application in the radar and communication system, resonance heating, thermos nuclear fusion plasmas, industrial fields. Vacuum diode is one of the most reliable and simplest ways to obtain microwave radiation from acute relativistic electron beam that does not require magnetic field. Their higher output power ability has been widely proven compared to other sources i.e., peak power varies from MW to GW. However,diodes are not efficient because power efficiency is restricted to a limited points is a serious flaw in the HPM applications, namely, effect on power supply [1,2]. Although it seems simple the vircator efficiency is a complex issue. Some basic restrictions weaker the competitiveness of the vircator output .MW radiation is normally broadband is standard configuration, this is because there is no inherent stabilization mechanism, and the output frequency is also susceptible to input voltage or current.

Cathode and anode are the significant part in the vircator as well as the geometry of the drift tube. In the drift tube cathode (Graphite materials, velvet etc) emits the electron which are accelerated towards the anode (semi-transparent materials) foil made of wires. Axial Vacuum diode is consisting of two parts, diode is responsible for an electron beam emission followed over the anode in a waveguide in charge of shaping microwave fields. For this operation it is mandatory that an electron beam current exceeding the space charge limiting current. Those electrons which emits from the cathode surface penetrates from the anode foil to form virtual gap cathode, the virtual cathode from the cathode twice the anode-cathode gap d_{ak}. A microwave emission generates due to the electron cloud oscillation. Vacuum diodes exhibit a low power efficiency. To overcome this drawback, Reflectors (Hollow Ring) are used in the cylindrical waveguide.

Many researchers are trying to enhance the conversion efficiency of standard vacuum diode by applying suitable technique [3, 4, 7]. By applying a longitudinal magnetic field electron travel in a straight direction. [5, 6, 8]. However, the results show that in the drift tube the presence of an axial magnetic field reduces the efficiency. [6]. It is very important to increase the generation of high-power microwaves in vircator by using different types of resonators, electrodes, and reflectors. Molchanov et al. simulated vacuum diodeto enhance the efficiencywith three hollow resonators [9].Champeaux et al. increasing the efficiency up to 21% by using multiple reflectors inside the waveguide [10, 11]. To increase the output power and carrier oscillation frequency we must make every effort to increase the density of electron in the virtual cathode. Alexander et al. studiednumerically of vacuum diode with coaxial conical electrode to concentrate on the electron beam[12] Choi et al. examine the improvement in the microwave power with the ring-type reflector [13] Jeon et al. using a bar reflector in the waveguide of co-axial vacuum diode[14]. The important factor is to increase the power collecting efficiency in the real experiment. Mumtaz S et al. Using a zone plate in the waveguide and enhancing the microwave power to twice by manage the emitted microwaves toward a focal point [15].

In this work we are working on two different ideas by using reflector in the drift tube. First, we made the reflector and working on its inner diameter and in the second part we show the change of reflector's position on effect microwave peak power, efficiency, frequency, and power delivered to TM_{01}mode. We studied numerically by using a 3D particle in cell module, CST.

2. SIMULATION SETUP

3-D PIC Simulation Tools: -

For designing the vacuum electronic HPM devices, computer simulation and modelling have been used. Vacuum diodes structures are studied and simulated commonly through EM PIC commercial tools. According to the Maxwell's equation, PIC simulation tools calculate the EM fields to give a solution to the equation of motion for the particles. Now a days, CST PS and Magic are the well tested 3D EM PIC codes in the field of MW device modelling.

Magic is dependent on the **F**inite **D**ifference **T**ime **D**omain algorithm, whereas **CST PS** and its **3D-PIC** solver are reducing complex structure's simulation time, and same level of accuracy by using a smaller number of mesh cells. **CST PS** a suitable and charming tool for virtual prototyping. In the past, magic code (**2D or 3D-PIC**) has been widely used in the field of diodemodel and their optimization [16, 17, 18, 19, 20]. Now a days **CST-PS** are used to designed and analysed new vacuum diode [21, 22, 23, 24]. In the forthcoming time, Research on novel vacuum diode scheme in axial configuration in which reflectors in drift tube are performed by **3D-CST –PS** code.

Note: Magic code calculations are conducted in the cylindrical coordinates (r, θ,z) while **CST PS** calculations are managed in Cartesian coordinated system (x, y, z).

In the model of axial Vacuum diode, the longitudinal axis is set to be z. the electron emission surface with diameter of 64mm is placed at the point where z=20mm. The circular waveguide length is 600mm which are greater than ten times to the targeted 5GHz MW emission wavelength to generate the TM_{01} mode in the waveguide. The axial vacuum diode is provided by incline function with excitation signal rising in 2ns and the total pulse duration are 25ns. The frequency of electron emission, the diode current and the output power are not only dependent on the design parameters such as the d_{ak} but also on the anode transparency as well as the cathode diameter [25 ,26,27]. In our case the transparency of anode is 70% and it represented a very thin mesh that reflects electromagnetic waves and anode diameter is equal to the inner diameter of the drift tube. The circular waveguide, inner and outer diameter are 90mm and 100 mm respectively. Cathode length and diameter are 20mm and 64 mm.Emission points on the cathode were set up to an approximate density i.e.

$$\frac{5729}{\pi r^2 c} = \frac{178\ \text{EPN}}{cm^2}$$

The electron is emitted by the surface of cathode by applying 420kV entrance via discrete voltage ports, which are ideally the same voltage level between the cathode and anode gap. Distance between the anode and cathode are called d_{ak} .PEC material are used for constructed the model.

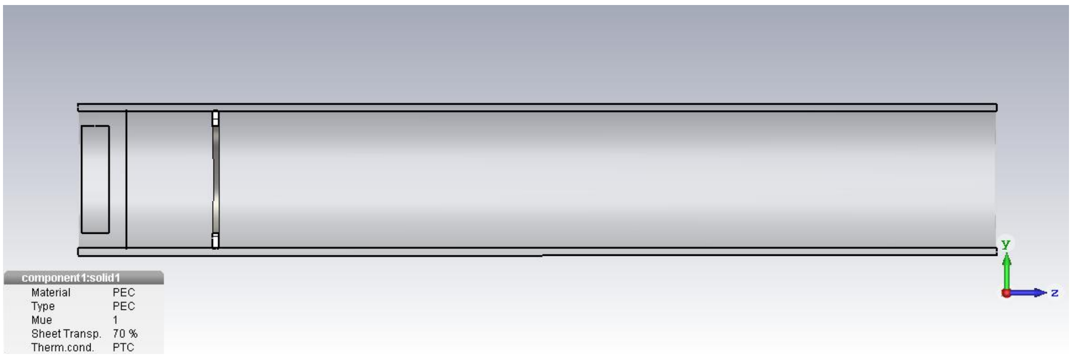


Fig 1: Axial Vacuum Diode

3. Results and Discussion: -

Reflector's Inner Diameter case

In the first model of conventional axial vacuum diode, we introduced the reflector in the waveguide placed at the distance$5d_{ak}$ from the cathode. The distance of anode from the cathode are 11.3mm and the reflector are 56.5 mm, and all other parameters are same as discussed in above. In this model we discuss on the peak power, efficiency, frequency and TM_{01}mode.

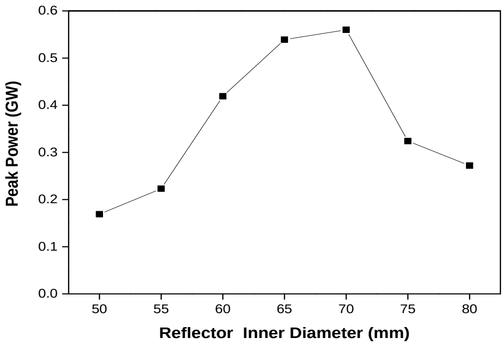


Fig 1

The graph 1a shows the result of microwave peak power with respect to change the inner diameter of the reflector. When the inner diameter is 50 mm then the peak power outcome at the end of waveguideis 168 MW, and it goes up as the diameter increases. There are two ideal positions on which the higher peak power(0.56GW) generate which are 65 mm or 70 mm and in the next two points peak power goes down. So as a reference for optimal results, we are using reflector with inner diameter 70mm in the next model.

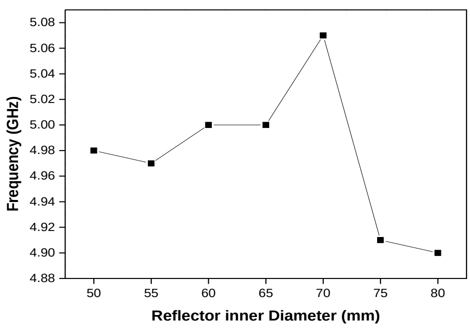
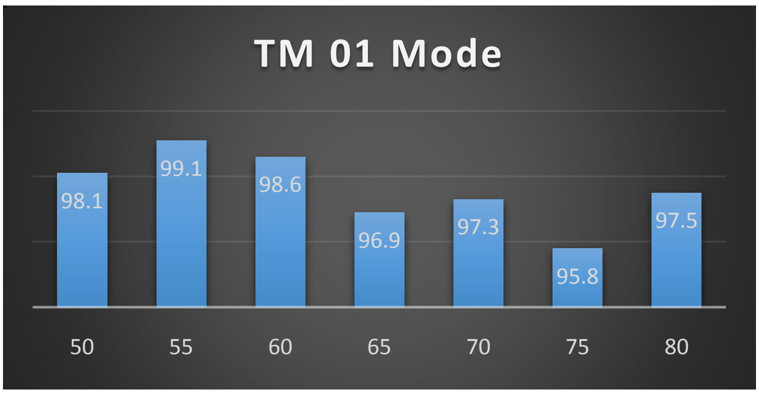
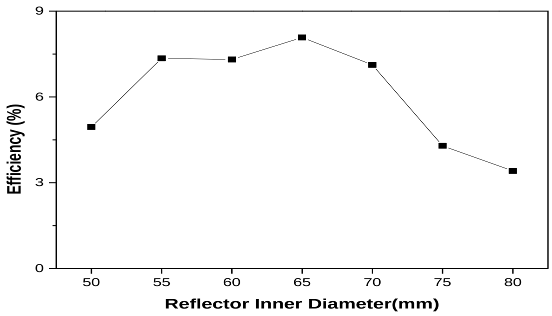


Fig 1b

The graph of 1b shows the change in frequency with respect to the inner diameter. It's almost the same frequency in all point just a little bit change and lie in the 4.90-5.07 GHz range. The maximum frequency coming as a result when the inner diameter is 70mm. That is the point on which maximum frequency and higher peak power results obtained.



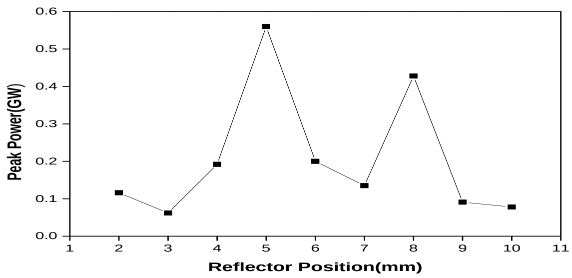
As in the simulation setup we are use eight transverse electric and magnetic modes and our priority are maximum power delivered in TM_{01} mode. So, in the above result is clearly show that maximum power delivered in TM_{01} mode and in our all model shows the maximum delivered power are greater than 95%.



The graph of 1c shows the energy efficiency with respect to the reflector inner diameter. This result is the proof of the niera's formula in which he shows that when the radius of drift tube is equal to the radius of cathode, so the maximum output power comes. So, in our model cathode diameter are 64 and the reflector are placed with in the inner diameter of the waveguide. So, reflector's inner diameter is drift tube. The result in which inner diameter of reflector are 65 mm which are nearly equal to the cathode diameter shows the higher energy efficiency which are 8.08 %.

Reflector's position variation case

In this model of axial diode, we set all the parameters are constant. As we already discuss in the reflectors inner diameter case that the suitable case on which higher microwave peak power and frequency results are reflector's inner diameter are 70mm. We are varying only the position of reflector from $2d_{ak}$ up to $10d_{ak}$ and studied the microwave peak power, frequency,TM_{01}mode and the efficiency.



The resultof 2a shows the behaviour of microwave peak power in simulation with the change in reflector's position. In our case peak power starts from 0.11 GW at when the reflector placed at a distance of $2d_{ak}$from cathode and result are change at every position. The peak power is maximum 0.55 GW when the reflector placed at $5d_{ak}$.

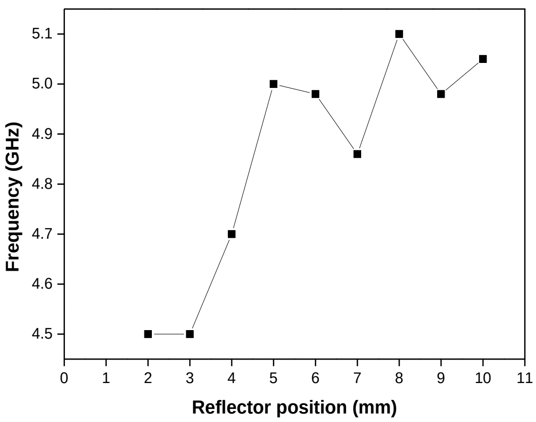
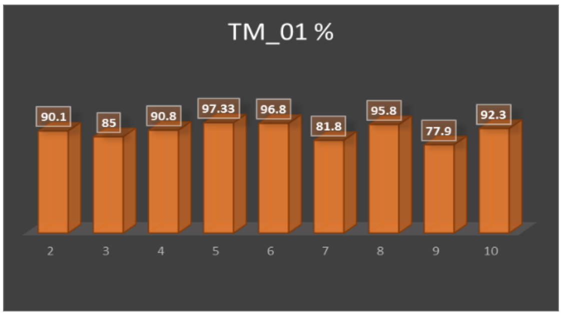
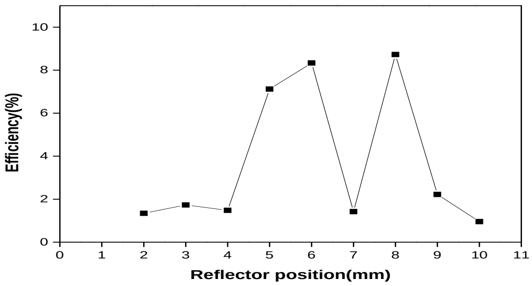


Fig 2b

The graph 2b shows the effect of frequency due to the reflector's position change. The minimum frequency is 4.5 GHz when the reflector is placed at the position of $2d_{ak}$ and $3d_{ak}$. The position on which the maximum peak powers are obtaining are $5d_{ak}$ when the frequency is 5 GHz.



As in the simulation setup we are use eight transverse electric and magnetic modes and our priority are maximum power delivered in TM_{01} mode. So, in the above result the maximum power delivered in TM_{01} mode at position $5d_{ak}$ which are 97.33 %.



This graph shows the efficiency of microwave output power with respect to the reflector position. We are firstly placed the reflector at $2d_{ak}$ and then change position with the addition of $1d_{ak}$ up to $10d_{ak}$. As already quoted in the literature that reflector efficiency is too low as compared to the other high power microwaves devices, as mentioned in the above result there are three points in which efficiency are greater than 7 %. The highest efficiency in the above result at $8d_{ak}$ which is 8.7% and the lowest efficiency which is less than 1 %, when the reflector at placed at $10d_{ak}$.

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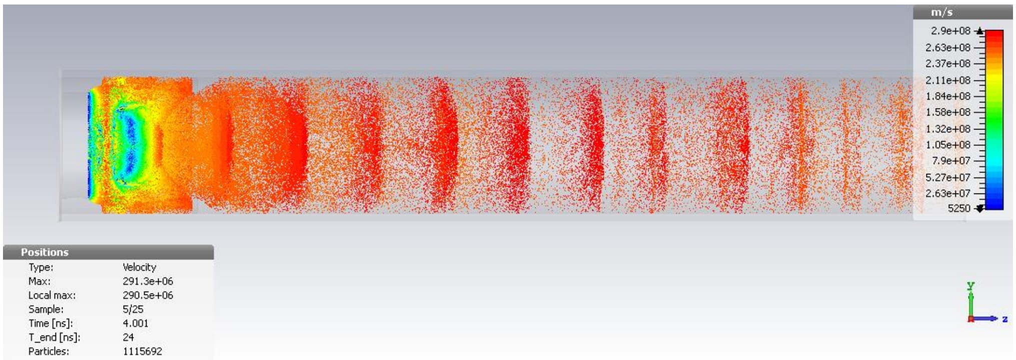

This picture shows the confirmation of virtual cathode formation in an axial vacuum diode.

4. Conclusion

In this work, the effect of a reflector diameter and their position change in an axial vacuum diode was studied numerically. The reflector with different inner diameter was studied using 3D PIC simulation code CST. The inner diameter of 65mm was observed to be most efficient result for high power microwave. The dominant oscillating frequency with inner diameter of reflector are 5GHz. In the reflector's position models, the best choice for optimum result is at $5d_{ak}$, which are 0.85 GW. The energy efficiency is 8.73 % by applying voltage 420Kv. The dominant emission mode isTM_{01} mode.

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