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COMPUTER SIMULATIONS OF CHARGED PARTICLE MOTION IN PULSED FIELDS

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Introduction

Analysis of the interaction between electric and magnetic fields and particles moving in a vacuum is fundamental to many problems in electrical and electronic engineering. Analytical models have been developed for many traditional devices such as cathode ray and vacuum tubes which rely on these interactions for their operation. Recently, however, many new areas of research based on particle-field interactions have emerged. In the pulsed-power field these include fundamental studies of the interaction of high frequency fields and static or moving charges [1], the synchronization of pulsed magnetrons for radar applications [2] and the development of new devices such as high-power microwave generating devices [3] or miniature vacuum devices based on silicon processing technology [4].

The operation of many of these new devices has become complicated and may be dependent upon several parameters. The analytical solution of such problems is often intractable and numerical simulation therefore has an increasingly important role to play in optimisation and design.

Transmission line modelling (TLM) is a numerical analysis technique which has been applied extensively to the solution of electromagnetic field problems[5,6,7]. It is a time domain approach and as such is ideally suited to studies of pulsed and transient effects. In this paper we explain how moving or static charge particles can be incorporated in a two-dimensional TLM electromagnetic field model. The new model is validated by applying it to a simple vacuum diode for which analytical results are available for comparison purposes.

Incorporation of Charged Particle Motion in Transmission Line Modelling

The solution of the electromagnetic field problem is based on a numerical two dimensional transmission line model (TLM) employing series connected nodes[7,8]. This discretizes the region to be studied into a mesh of step length ΔL as illustrated for a simple planar vacuum diode in Figure 1. Time is stepped in intervals Δt where $\Delta t = \Delta L/C$ is the time a wave takes to propagate from one node to an adjoining node. An electric field can be set up inside this region by applying the voltage source V_a to the anode. An additional contribution to the field arises from charges injected into the modelled region from the cathode.

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At a particular time instant the TLM is used to find the electric field at each mesh point in the usual way. Once the electric field and any applied z-directed magnetic field are known at each mesh point, the x and y components of the force on each charge can be calculated. For each modelled charge the computer program developed stores the charge size and its calculated velocity, exact position and nearest node position. A further field calculation need only be performed for the duration of any transient effects or when the applied voltage or the nearest-node position of any charge changes. Predictions of when these discretized charge positions will occur are automatically made within the computer program which makes the computational process very efficient. To model the movement of a charge Q from one mesh point to another a current I is allowed to flow between the two nodes considered for time kΔt where I = (Q/kΔt) and k is the number of time steps over which the charge is moved.

Results

A diode with 3 cm wide plates separated by 1 cm was studied. The region between the plates was divided into a regular mesh with node separation 0.1 cm in both x and y directions. The width of each electrode was one node spacing. A uniform electric field was set up between the plates of the diode by application of a static voltage V_a. Charges were injected from the cathode to the first row of nodes to give an emission current density [9].

$$J=A_0T^2\exp\left[\frac{-W}{kT}\right] \qquad (1)$$

where A_0 is a constant dependent on the cathode material, T is the assumed cathode temperature in degrees kelvin, k is Boltzmann's constant and W is the work function of the cathode material.

Because the electric field is only y directed the uniform injection taken effectively reduces the model to a one-dimensional one if no magnetic field forces are considered. The static diode current arising was measured in two ways; directly as the sum of the current flowing in the two wires A and B and as the rate of flow of charge over a given period at any mesh point. These computed currents where found to be identical in the steady state.

Figure 2 shows the calculated voltage distribution between the cathode and anode for an applied voltage of 50V with no electron emission and then emission corresponding to a tungsten cathode operating at temperatures of T_1 = 2000 K and T_2 = 2150 K. The curves show clearly the effect of space charge in lowering the potential and changing the sign of the electric field near the cathode for high injection and agree with theoretical predictions [9,10]. Figure 3 shows the I-V characteristic of a diode with a tungsten cathode operating at a temperature of 2000K. The space charge limited and saturation regions anticipated can be clearly seen. The saturation current I_{sat} was also found for several tungsten cathode temperatures in the range 1750-2250K. From the results obtained the straight line relation between I_{sat}/T^2 and 1/T (Equation 1) was plotted as shown in Figure 4. The slope of this plot produces the correct value for the work function of tungsten further validating the numerical analysis.

Conclusion

Static or moving charged particles have successfully been incorporated in a transmission line model for numerical electromagnetic field computations based on a two-dimensional series connected node. The approach has been validated by applying it to a simple vacuum diode for which analytical results can be obtained. The time-domain nature of the transmission line approach makes the new computer program developed ideal for simulating pulsed power phenomena and devices.

References

1 A F Kurin: "The dynamics of the electric and magnetic components of the high-frequency field in the case of interaction with moving charges" Radiotekhnika i electronika, No 1, pp 126-131, 1989

2 B Vyse, V H Smith, M O White: "The use of magnetrons in coherent transmitters" Proc Military Microwave Conf, pp 217-222, 1982

3 B M Marder: "Simulated behaviour of the magnetically insulated oscillator" J Appl Phys 65, 1338-1349, 1989

4 R Stengl, H W Meul, W Honlein: "Microcavities with field emitters sealed by silicon wafer bonding" Elec Lett 27, pp 2209-2210, 1991

5 P B Johns, R L Beurle: 'Numerical solution of two dimensional scattering problems using a transmission-line matrix' Proc IEE, 118, pp 1203-1208, 1971

6 W J R Hoefer: 'The transmission line matrix method - theory and applications' IEEE Trans MTT-33, pp 882-893, 1985

7 C Christopoulos: 'Field analysis software based on the transmission-line modelling method'In Advances in Electrical Engineering Software ed P P Silvester Comp. Mechanics Publ and Springer-Verlag 1990, pp 135-148

8 P Naylor: 'Using 2-D series TLM for modelling TE modes in dielectric and lossy environments' Elec Lett 27, 1499-1501, 1991

9 J Millman: 'Vacuum tube and semiconductor electronics' McGraw-Hill, 1958 pp 1-59 and 92-112

10 H J van der Bigl: "The thermonic vacuum tube and its applications" McGraw-Hill, 1920

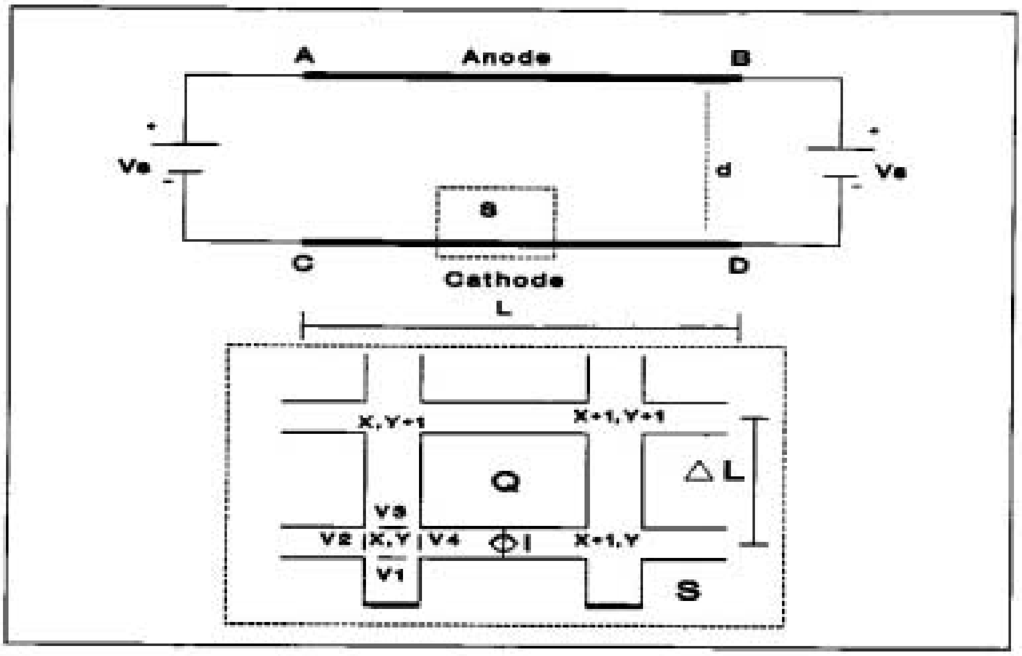

Fig.1 Discretization of Planar Vacuum diode into a two dimensional TLM model.

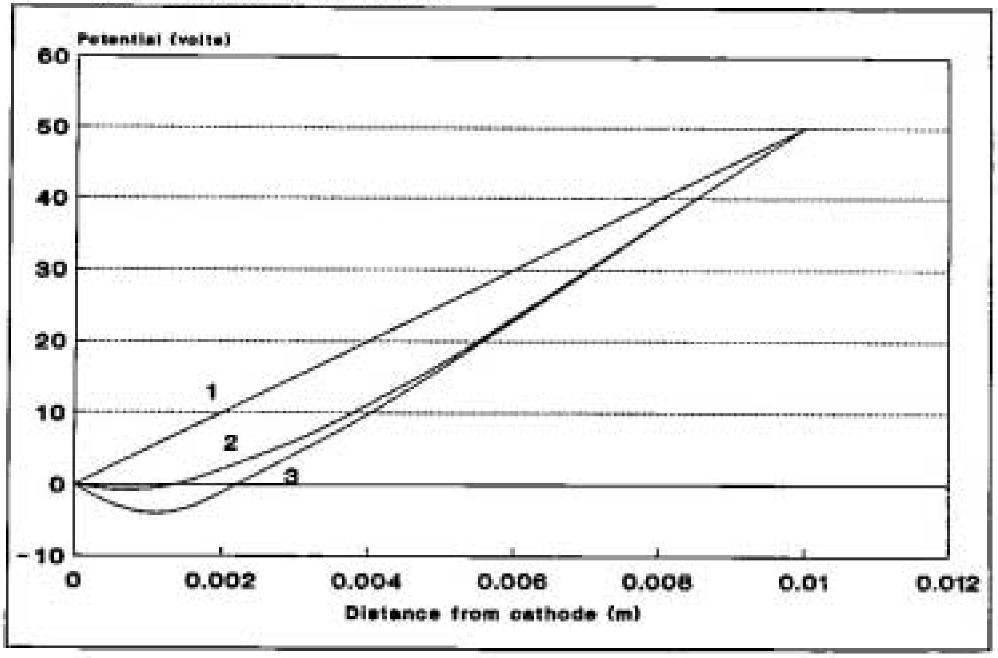

Fig.2 Variation of Potential with distance from the cathode for: 1) No emission, 2) cathode temperature T1=2000 K, 3) cathode temperature T2=2150 K.

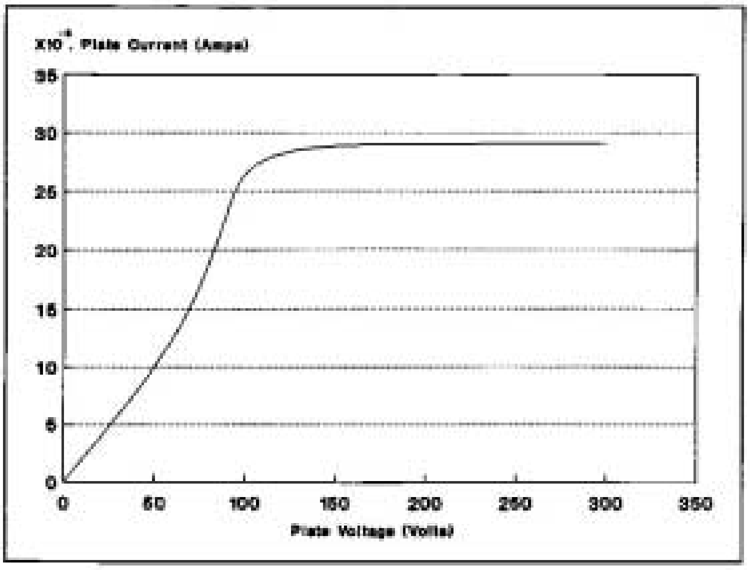

Fig.3 I-V Characteristic of a planar diode studied for a tungsten cathode operating at 2000 K.

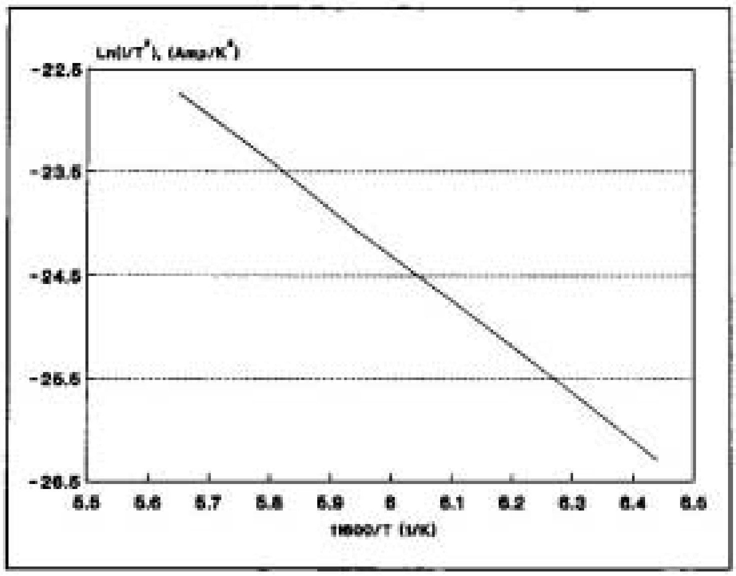

Fig.4 Plot of Ln(Isat/T^2) against (1/T) for the planar diode studied.