1-3 DYNAMICS OF GUNN DOMAINS IN FUNCTIONAL BULK OSCILLATORS

by

Masakazu Shoji
Bell Telephone Laboratories, Incorporated
Murray Hill, New Jersey 07974

With the development of functional bulk devices it became necessary to know how Gunn domains move in two-dimensional device structures. In this paper we present a simple theory describing the time evolution of such "two-dimensional" domain shapes and verify the theory by showing data from probing experiments.

The narrow rectangle ABCD in Fig. 1 intersects perpendicularly to a "two-dimensional" Gunn domain at the point $\vec{P}$. We investigate whether the velocity of the domain segment can be found by a simple one-dimensional theory applied to the rectangle. The electric field component parallel to the domain, $E_{\|}$, is not limited to zero and is different at the two sides $\overline{AB}$ and $\overline{CD}$. Consequently, current and electric flux are injected at each point of the rectangle. A simple perturbation calculation can be carried out to find how much the velocity is influenced by this current and flux injection. A numerical estimate for the calculation shows that the domain velocity is within a few percent of that of a one-dimensional domain having the same domain potential in a uniform sample. Since the latter velocity tends to a constant v_0 when the domain potential is high, the motion of a thin domain is described by

$$\frac{d\vec{P}}{dt} = v_o\vec{N} \tag{1}$$

where $\vec{N}$ is the normal to the domain at the point $\vec{P}$. If the domain shape on the x-y coordinate system of Fig. 1 is analytically represented by $y = y(x,t)$, we find the following equation to be satisfied by $y(x,t)$.

$$1 + \left\{\frac{\partial y(x,t)}{\partial x}\right\}^2 = \frac{1}{v_o^2}\left\{\frac{\partial y(x,t)}{\partial t}\right\}^2. \tag{2}$$

If the domain shape at $t = 0$ is given, the subsequent shape can be found by solving Eq. (1) subject to the requirement that $y = y(x,0)$ represents the given initial shape. The solution of the domain shape is straightforward when the width of the bulk is much larger than the cathode-anode distance and consequently the effects of the device edge are negligible. When the width is small, however, the device edge influences the solution in the following manner. Line $\overline{AA^*}$ in Fig. 2 indicates a domain at $t = 0$. After a short time it moves to $\overline{BB^*}$. Since the electric field at the device edge must remain parallel to the edge, a image dipole $\overline{DD^*}$ must be placed at the opposite position of $\overline{BB^*}$ with respect to the device edge $\overline{CC^*}$. It may be shown by elementary electrostatics that the field on $\overline{CC^*}$ has a maximum at E. Inside the device the field maximum occurs along $\overline{BE}$ and a new domain segment is nucleated perpendicular to the edge. As time goes on the nucleated part propagates in the direction $\overline{CC^*}$ while the domain farther inside the bulk moves in the direction $\overline{AB}$. This results in a bent domain as shown by $\overline{FF^*F^{**}}$ in the figure. When the angle $\angle CAA^*$ between the domain and the device edge is less than 90° the domain shape is not influenced by the device edge as the domain effectively moves through the edge.

The experiments verifying the above theory were performed by utilizing a resistive probe described by Thim and Barber. The length of the samples ranged from 0.5 mm to 2 mm. Figure 3 shows the domain shape variations with time as observed in a slanted-cathode device. The variation in shape can be explained by assuming that each point on the domain moves in a direction normal to the domain with a constant velocity. This can be seen from Fig. 3 by studying separate parts of the domain. The upper part above the broken line, as observed from the anode side, resembles concave circular arcs of decreasing radii as the domain moves. The part below the broken line resembles convex arcs with increasing radii as the domain moves. Figure 4 shows how domain shapes are affected by sharp device bends. When a domain travels through a bend the domain's upper part bends and realigns itself perpendicularly to the upper device edge as described in the theory. The lower part, however, tends to maintain its original orientation, since the angle between the domain and the lower device edge is less than 90°.

The theory of "two-dimensional" domain motion was confirmed by many other experimental results. These observations are shown by a 16 mm movie at the conference.

Figure Captions

Fig. 1 "Two-dimensional" Gunn domain.
Fig. 2 Domain nucleation at the device edge.
Fig. 3 Domain shape variations in a slanted-cathode device.
Fig. 4 Domain shape variations in a sharp band.

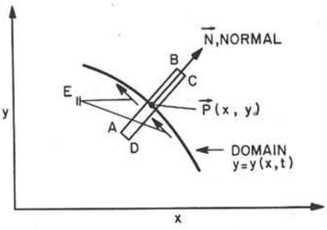

Fig. 1

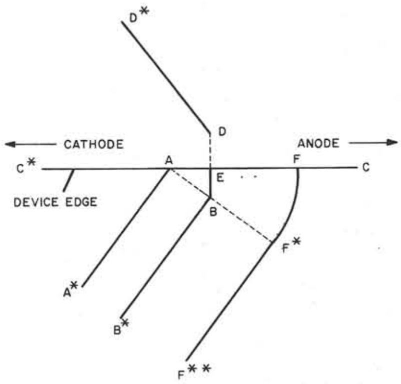

Fig. 2

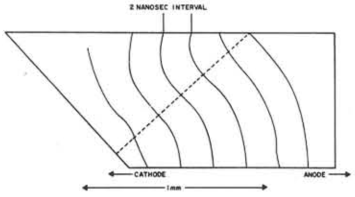

Fig. 3

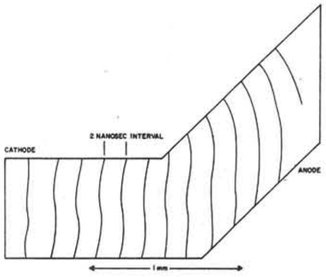

Fig. 4