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THE MECHANISM OF GAIN DEPRESSION IN CONTINUOUS-STRIP ELECTRON MULTIPLIERS

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A theory of high-output-current gain depression in continuous-strip electron multipliers is based on the assumption that for a particular device the local gain is a function solely of the local axial field. Substantiative experimental data are presented.

The high-count-rate or high-output-current operation of continuous-strip electron multipliers[1,2] recently has received considerable attention.[3–5] Gain depression (nonlinearity) has been observed at high-output-current levels, but no satisfactory mechanism has been proposed. In this letter, we develop a theory of gain depression that is consistent with experimental data. The theory is not dependent upon surface-charging[4] hypotheses. Although the analysis is performed here for tubular (channel) multipliers, it can also apply to nontubular continuous-strip multipliers if minor modifications are made.

Let z be the axial coordinate of a tubular multiplier of length L. A high voltage V applied along the tube produces a strip current i in the inner conducting surface resulting in an electric field λi, where λ is the resistivity per unit length. For fixed V, the following constraint applies:

$$\lambda \int_0^L i\, dz = V. \tag{1}$$

Gain is defined by

$$g = I_L / I_0, \tag{2}$$

where I_0 and I_L are the free-electron input and output currents, respectively. Since a local exponential gain factor m (per unit length) can be defined by

$$m = d[\ln I(z)]/dz, \tag{3}$$

where $I(z)$ is the free-electron current, the gain can be expressed as an exponential function of m, i.e.,

$$g = \exp\left(\int_0^L m\, dz\right). \tag{4}$$

Physically, m may be thought of as the ratio of the free-electron current leaving an infinitesmal disk dz to the current entering it. The law of the conservation of currents yields

$$i + I = i_0 = I_0 = i_L = I_L = K(i_0), \tag{5}$$

where K, the total current, is a function of the input strip current i_0. We assume that a single local gain factor m applies everywhere in the channel and that m is a function only of the local field $\lambda i(z)$, i.e., $m = m(\lambda i)$. These assumptions limit this analysis to multipliers operated at gains below space-charge saturation,[6] and they require that the axial-field variations be sufficiently slow so that the associated radial fields are negligible. Using Eqs. (3) and (5) we can write

$$-\int_0^L dz = \int_{i_0}^{i_L} \frac{di}{(K-i)m(\lambda i)}, \tag{6}$$

and rewriting Eq. (1), we obtain

$$\int_{i_0}^{i_L} z\, di = i_L L - V/\lambda . \tag{7}$$

Equations (6) and (7) are independent with L and λ the fixed device constants; V selectable; and i_0, i_L, and K the variables. One can formally solve Eqs. (6) and (7) for i_L and K as functions of i_0, i.e.,

$$K = K(i_0, V) \quad \text{and} \quad i_L = i_L(i_0, V). \tag{8}$$

From Eqs. (2), (5), and (8) the gain can be formally calculated by

$$g(i_0, V) = [K(i_0, V) - i_L(i_0, V)]/[K(i_0, V) - i_0]. \tag{9}$$

Thus, if the gain factor $m(\lambda i)$ can be obtained as a function of the local field, the gain, strip currents, and the free-electron currents can be predicted

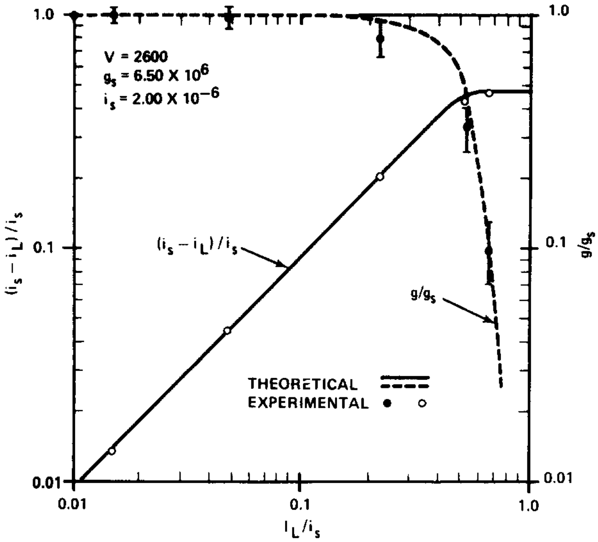

FIG. 1. Comparison of experimental gain depression data and theoretical curves according to proposed mechanism. The gain g normalized to the no load gain g_s and the normalized difference between the no-load strip current i_s and the strip current at the output end i_L are plotted as functions of the normalized output signal (free electron) current, I_L/i_s. The subscript s denotes the value of the parameter indicated at (nominal) no-load conditions.

for any operating voltage.

We have found that experimentally determined values of $m(\lambda i)$ may be approximated by a parabolic curve, $m = a + bi + ci^2$, where a, b, and c are device constants. For parabolic functions $m(\lambda i)$, Eqs. (6)–(9), can be solved in closed form; however, these solutions are too lengthy to be given here.

In an experimental test of the analytical model, we operated a standard channel electron multiplier at unity gain until a total charge of 7×10^{-5} C had passed through the multiplier. By processing in this fashion we were able to uniformly scrub the surface[7] which resulted in a stable multiplier with homogeneous surface properties. To obtain the function $m(\lambda i)$ experimentally, we operated the multiplier at very low output current levels and measured the gain as a function of the electric field. Since for $I_L \ll i_L$ the electric field is uniform throughout the tube, Eq. (4) can be rewritten as $m(\lambda i) = (1/L) \ln g(\lambda i)$.

A parabolic fit was obtained for these experimental $m(\lambda i)$ values and was then inserted into the theoretical gain-depression solutions [Eqs. (8) and (9)]. The resulting theoretical curves of gain and output strip current as functions of output signal current are given in Fig. 1 for $V = 2600$. Also plotted in this figure are the experimental points that we obtained by measuring output strip current and free-electron (signal) current while varying the input signal current.

The excellent agreement between the experimental values and the predicted curves supports the proposed model of gain depression, which assumes that the local gain factor m is a function solely of the local axial field. In addition, this agreement demonstrates that a more sophisticated model hypothesizing highly resistive layers or complex radial fields is not necessary to describe high-output gain depression. Our model predicts that the output-current capability (the count-rate capability) could be increased significantly by increasing the strip current i_s. This can be accomplished in practice by decreasing the strip resistance.

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