Prediction of Excess Noise Factor and Frequency Response for Thin Avalanche Photodiodes

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SUMMARY

Recent experimental measurements from InP and InAlAs avalanche photodiodes (APDs) with thin multiplication regions, collected by J.C. Campbell and collaborators at the University of Texas at Austin, show that, for a fixed gain the excess noise factor is significantly lower than that predicted by the conventional McIntyre theory [1]. The observed dependence of the noise on the multiplication-region width cannot be explained using the conventional theory in which the excess noise factor is a function only of the mean gain and the ionization coefficient ratio. In the dead-space-multiplication theory (DSMT) [2], a carrier must travel a certain distance, called the dead space, before gaining sufficient energy for impact ionization to occur. Because this dead space regularizes the ionization locations, the randomness of the avalanching mechanism is reduced. For thin multiplication-region APDs, this effect is proportionally higher and thus the noise is lower. We applied the DSMT to the experimental results for GaAs and AlGaAs [3] and more recently for InP and InAlAs APDs. We were able to fit the ionization coefficients associated with devices of various thicknesses, as a function of the electric field, within the confines of a single exponential model, as shown in Fig. 1 (for brevity, only the electron ionization coefficient for InP is shown). Using these width-independent ionization coefficients, the DSMT then correctly predicts the gain-noise characteristics of thin APDs for a variety of multiplication region widths. Figure 2 shows the DSMT predictions and the experimental results for InP APDs of varying thickness. Furthermore, in conjunction with the width-independent ionization coefficients, the DSMT characterization of the statistics of the APD impulse response [4] is used to predict the frequency response. As the multiplication-region thickness decreases, the DSMT estimate of the 3-dB bandwidth becomes significantly lower than the conventional estimate obtained by using the ionization coefficients for bulk material, as shown in Fig. 3. For example, as seen in Fig. 4, a reduction of 30% in the 3-dB bandwidth is predicted for a 100-nm GaAs device.

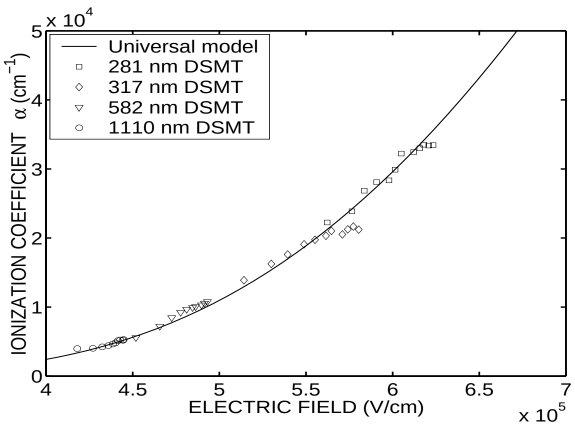

Figure 1. Electron ionization coefficient (α) of InP as a function of the electric field.

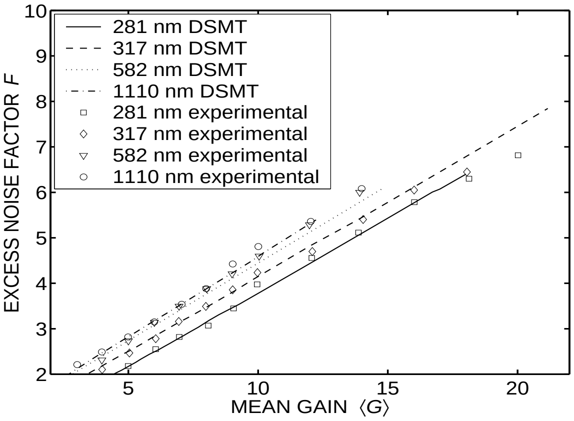

Figure 2. The DSMT predictions of the gain vs. noise characteristics for thin InP APDs.

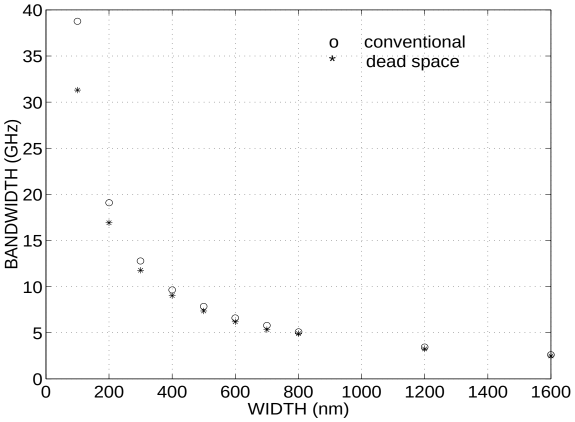

Figure 3. Comparison between the conventional and DSMT predictions of the 3-dB bandwidth for GaAs APDs of varying thickness.

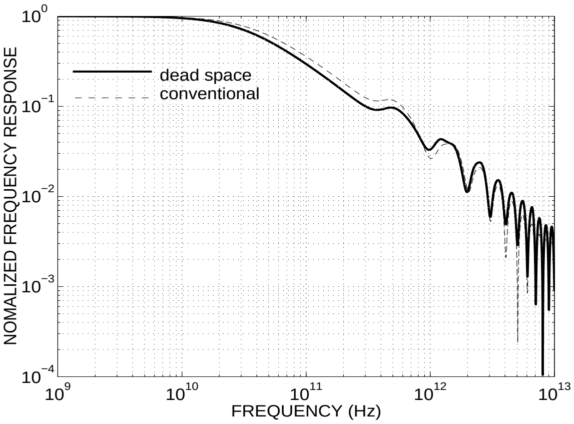

Figure 4. Conventional and DSMT predictions of the frequency response for a thin (100nm) GaAs APD.

References

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