# GaAs MESFET Photoresponse to CW Laser Probe

D Abbott
*Department of Electrical and Electronic Engineering, University of Adelaide, SA*
K Eshraghian
*Centre for Very High-Speed Microelectronic Systems, Edith Cowan University, Joondalup, WA*

**An effect, in planar GaAs MESFETs, whereby a sharp increase in optical gain at the transistor edges occurs, is reported. This gain effect only manifests when a large resistor is inserted in series with the gate, to produce the conditions for photovoltaic gate biasing. The mechanism for increased gain, at the edges, is suggested to be due to carrier photogeneration in the substrate that is subsequently collected by the gate. Application in the area of X-Y addressable transistor array imagers, motion detectors, optical neural nets, GaAs X-ray detectors etc. is possible, for increased photosensitivity.**

## 1 Introduction

Photoresponse of GaAs MESFETs has received much attention due to potential application in high speed optoelectronic communications, OEICs and optical tuning of microwave devices. Various optical gain mechanisms have been reported, including photovoltaic gate biasing. This effect occurs when the gate photocurrent follows through an external series gate resistor, $R_g$, thus increasing the gate voltage and hence drain current. To produce a significant increase in drain current, a large $R_g$ introduces a large RC time constant which typically causes the response to roll off in the 10-100 MHz range. Consequently, as most researchers have concentrated on high speed applications, photovoltaic gate biasing has been regarded as being of limited merit [1] and has not received full attention. However, as the data rate of a typical imager is less than 10 MHz, photovoltaic gate biasing can potentially be used to increase the sensitivity of such devices. Furthermore, we discovered that the sensitivity is increased in the region where a gate overhangs the transistor edge. This new knowledge can help to maximise the benefits of this effect to imaging devices.

This new edge effect was discovered when a GaAs MESFET was scanned with a focussed laser spot. The planar MESFETs used have a fingered structure with 5 gates, $L = 0.8$ $\mu$m and overall $W = 400$ $\mu$m. The channel (depth, $d = 0.1$ $\mu$m and doping, $N_d = 1.2\times10^{17}$ cm$^{-3}$) is situated on a semi-insulating (SI) GaAs:EL2 substrate, with no buffer layer. The source-gate and drain-gate separations are both 1.3 $\mu$m.

## 2 Results

Fig. 1 shows a length scan across a transistor with 5 fingers. As the gate length, 0.8 $\mu$m, is smaller than the laser spot diameter, 2 $\mu$m, the peaks of the curve correspond to when the spot exactly straddles the gate. A 1 M$\Omega$ resistor is included, in series with the gate, to produce an extrinsic gain effect by photovoltaic self-biasing. This gain was deliberately introduced to accentuate the peaks and troughs. It is notable that the gain at a trough is at best 2, whereas the gain at a peak is at best 5, ie. the gain is more than doubled when the laser spot straddles the gate. This indicates that maximum sensitivity is obtained by illuminating the gate edges.

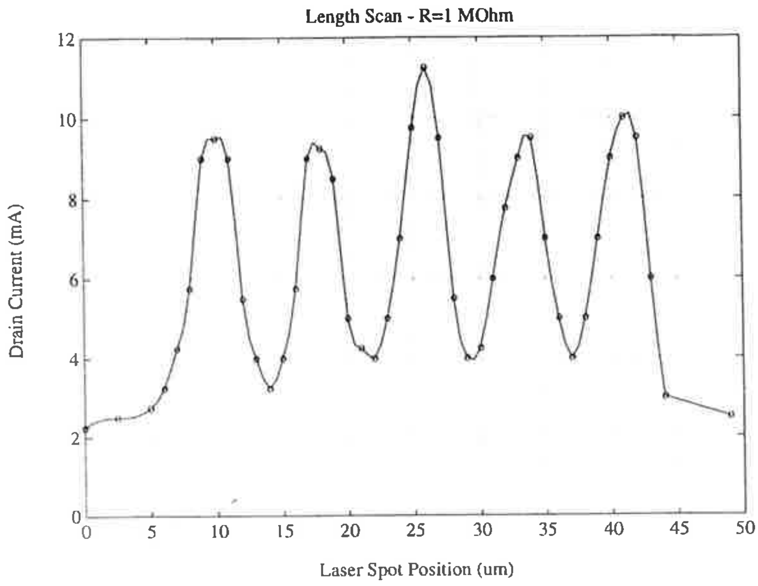


Figure 1: Transistor length scan with focussed laser, 678 nm @ 0.125 mW, 2 $\mu$m diameter spot size. 1 M$\Omega$ series gate resistor. $V_{gs}$=-0.8 V, $V_{ds}$=0. 6V.

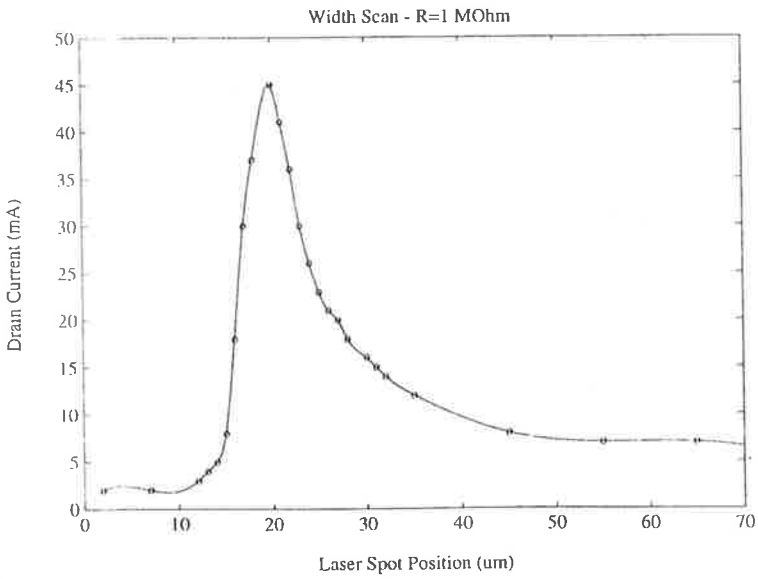


Figure 2: Transistor width scan with focussed laser, 678 nm @ 0.125 mW, 2 $\mu$m diameter spot size. 1 M$\Omega$ series gate resistor. $V_{gs}$=-0.8 V, $V_{ds}$=0.6 V. Transistor edge corresponds to 20 $\mu$m on the x-axis.

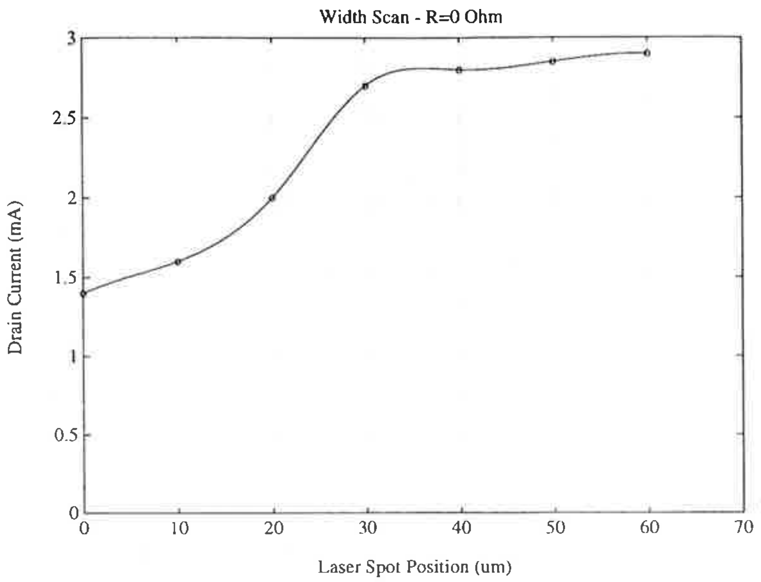


Figure 3: Transistor width scan with focussed laser, 678 nm @ 0.125 mW, 2 $\mu$m diameter spot size. No series gate resistor. $V_{gs}$=-0.8 V, $V_{ds}$=0.6 V. Transistor edge corresponds to 20 $\mu$m on the x-axis.

Fig. 2 was obtained by scanning the laser across the transistor width and highlights a significant gain effect. From a gain of about 3, the gain dramatically increases to over 20, at the transistor edge. This is a new effect that has not been reported in the literature, by other workers. We have patented a novel imager design that utilises this new effect [2] to create an increased sensitivity.

An important result from Fig. 2, for the imager design, is that the left hand side of the curve decays rapidly over a distance 5 $\mu$m, as the spot moves away from the transistor edge and onto the substrate. This decay distance is much smaller than the anticipated imager pixel size (40 $\mu$m sq) and is an excellent feature required for an imager with low pixel crosstalk and good spatial resolution.

With reference to Fig. 3, we see that the gain drops off at the edge, in the absence of the series resistor. This demonstrates the photoductive component of the photoresponse, showing that it is small. The fact that roll-off commences a few microns before the edge is reached could possibly be explained by tapering of the channel.

Fig. 4 shows the photovoltaic self-biasing (or 'gate biasing') effect, as a function of series resistance. The higher curve, corresponding to the transistor edge, begins to plateau at higher resistances, as the gate approaches the forward bias regime. The edge clearly produces a higher gain for all resistor values. Due to the large series resistor required to produce a significant gain, high frequency operation is not possible and so photovoltaic gate biasing has not received much attention in the literature.

However, photovoltaic gate biasing is of interest in a low frequency GaAs X-Y addressable transistor array for solid-state imaging. The pixels in such an imager can be configured to optimise the edge gain mechanism, thereby increasing the sensitivity of the device. With careful development, a GaAs imager utilising a conventional planar MESFET technology may potentially offer increased radiation hardness, reduced dark current and the convenience of integration with high speed GaAs image processing cells.

We have discovered a new finding that the optical gain sharply increases where the gate crosses the transistor edge. This only occurs with a series gate resistor inserted, to produce the conditions for photovoltaic gate biasing. This finding suggests that carriers generated in the substrate, beyond the transistor boundary, are able to be collected by the gate depletion region. This edge effect is observed in a planar GaAs MESFET and is quite different to the edge gain effect observed in mesa GaAs MESFET structures [3, 4].

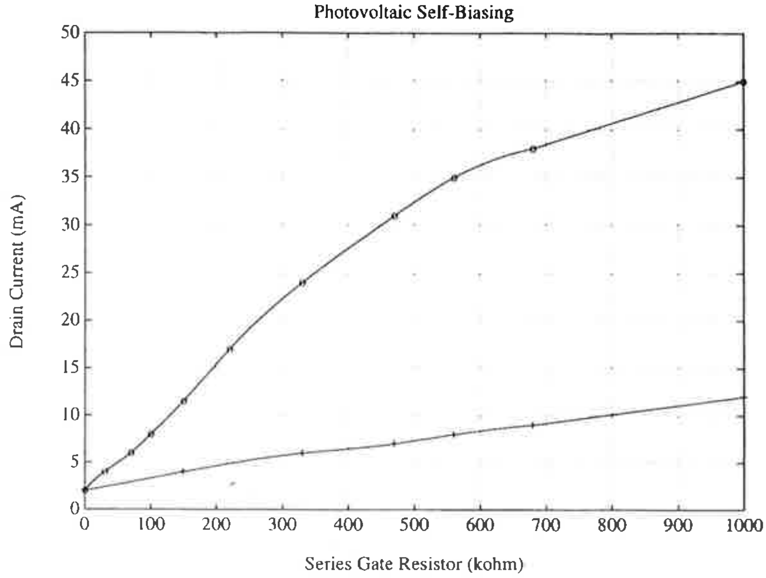


Figure 4: Response against gate series resistor. 678 nm @ 0.125 mW, 2 $\mu$m diameter laser spot size. 1 M$\Omega$ series gate resistor. $V_{gs}$=-0.8 V, $V_{ds}$=0.5 V, 'o'=transistor edge, '+'=transistor middle.

We proposed a generalised model for the photoresponse of a GaAs MESFET [5] which considered a photovoltaic (PV) effect in the gate depletion region, a photoconductive (PC) effect in the channel and two main substrate effects (trapping by defect centres and substrate/channel depletion region collection). In order to explain the observed effects, in our present case, we are able to invoke the gate depletion region and substrate/channel depletion region parts of the model.

Note that although the gates are opaque, the peaks actually correspond to a position where the laser spot is exactly centred on the gate (Fig. 5). This is because the spot diameter is larger than the gate length and thus a central position maximises the amount of light to the gate edges, where the depletion region extends outwards, from under the gate, and is exposed. Also holes diffusing in the channel, that are generated close to the gate edges, can be collected by the gate depletion region. Even though the diffusion length of holes in the channel is 1.8 $\mu$m, holes that are far from the gate are more likely to be collected by the channel/substrate depletion region because the channel depth $d \ll 1.8$ $\mu$m – therefore there is a very narrow capture angle for gate collection.

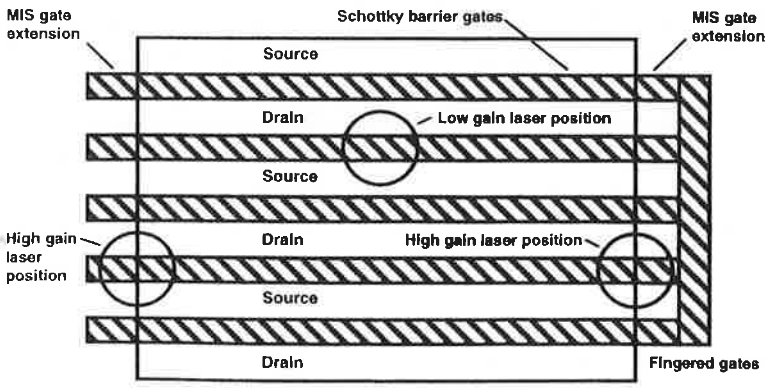


Figure 5: laser spot positions for high & low gain drain current response.

According to our working hypothesis, the high gain peak can be explained if there are holes generated in the substrate, outside the transistor, being collected by the gate. Therefore we postulate the existence of a depletion region in the substrate that has connecting electric field lines with the edge of the gate depletion region. This new depletion region is assumed to be formed under the MIS structure, where the gate extends over $Si_3N_4$, outside the transistor. The channel/substrate depletion region must also connect at the edge and, given a depth of about 2 $\mu$m, we estimate that the depletion region would need to protrude from under the MIS electrode by about 0.2 $\mu$m to account for the high gain peak.

# 3 Conclusion

In conclusion, we have reported a new optical edge gain effect in planar GaAs MESFETs, useful in low frequency applications, such as in an X-Y array imager. Photocollection under the MIS gate extension, outside the transistor, is suggested to explain the gain effect. Future models for the photoresponse in planar GaAs MESFETs, that attempt to generalise all operating conditions, must take into account this new effect.

The original contribution is that we have discovered a new internal gain effect in GaAs MESFETs. As well as having implications for increasing the sensitivity of photodetectors we have exploited the gain effect to estimate that the carrier diffusion length in the semi-insulating substrate is less than 10 $\mu$m – the realisation of this fact is important for good spatial resolution in high definition television (HDTV) sensors.

The observation that there is some variation in the edge-effect from transistor to transistor and the discussion of the complicated active photoresponse of the MESFET immediately suggests an important design constraint for the imager: the photoresponsive element, in the first instance, should be a simple diode structure. Utilising a full active MESFET photodetector will present unwanted non-uniformities and thus fixed-pattern-noise (fpn) in the final imager. However, utilisation of the edge-effect would be appropriate in simple motion detectors where the signals are thresholded and thus pixel uniformity is not crucial.

# 4 Acknowledgement

This work was supported by the Sir Ross and Sir Keith Smith Foundation and the ARC.

# References

[1] R.B. Darling and J.P. Uyemura, "Optical gain and large-signal characteristics of illuminated GaAs MESFETs," *IEEE J. Quantum Elec.*, **vol. QE-23**, no. 7, pp. 1160-1171, 1987. (refer p. 1167, para. 2)

[2] D. Abbott, "Gallium Arsenide MESFET Imager," *Prov. Patent*, PK8660, Aug. 1991.

[3] L.D. Flesner, N.M. Davis and H.H. Wieder, "High Speed Repsonse of a GaAs Metal-Semiconductor Field-Effect Transistor to Electron Beam Excitation," *J. Appl. Phys.*, **vol. 53**, no. 5, pp 3873-3877, 1982.

[4] J-M. Rouger, R. Perichon, S. Mottet and J.R. Forrest, "Etude du comportment du transistor a effect de champ au GaAs sous injection optique quasi ponctuelle," *Ann. Telecommun.*, **40**, no. 3-4, pp. 88-97, 1985 (in French).

[5] A. Adibi and K. Eshraghian, "Generalised model for GaAs MESFET photodetectors," *IEE Proc.*, **vol. 136**, Pt. G, no. 6, pp. 337-343, 1989.