Measuring Electro-luminescence and photosensitivity of trap sites in GaN Devices

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Abstract

Here we present a system allowing simultaneous measurement of the RF and optical behaviour of on-wafer devices, which permits Fully Active Harmonic Load-Pull techniques to be employed while either observing optical phenomena such as Electroluminescence, or applying optical stimuli for trapping investigations. Full access to the backside of the wafer is achieved, allowing measurements on devices with source coupled field plates or air bridges, which normally obscure the gate region. Electroluminescence can be observed with an ultra-low light camera or a spectrometer. Previously it has been shown that traps in GaN devices can react to light at 385nm, here the wavelength sensitivity is investigated. The test device was a GaN on silicon carbide HFET.

Introduction

It has previously been shown that trapped charges within GaN devices can respond to light stimulation [1]-[2], and that the measurement of electroluminescence (EL) due to hot electrons is a useful tool for reliability analysis [3]. The study of both of these phenomena is impeded by the presence of a field plate over the gate region, and source-ground air bridges, as shown in fig. 1, so a means of observing or stimulating the channel region from the back-side of the wafer would be advantageous. While EL analysis under RF operation was achieved by Brazzini et al, [4], this was under passive load-pull operation, which restricts the power levels and modes which can be investigated. Here we demonstrate the accurate measurement of RF I-V waveforms in a Fully Active Harmonic Load-Pull environment under pulsed or CW conditions while simultaneously performing EL microscopy or spectroscopy.

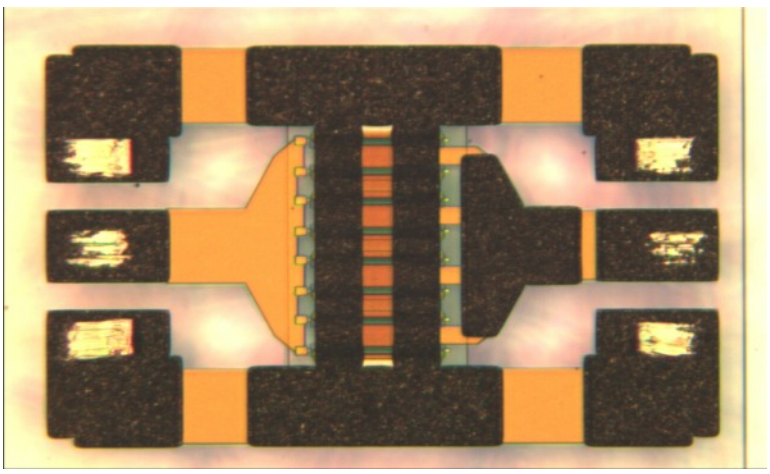

Figure 1 A 8x125 UMS GaN die showing the air bridges obscuring the gate region

The main difference between this system and previous equipment is that the probe station was redesigned specifically to allow good access to the backside of the wafer, while not compromising the other requirements for a wafer probe station. A stable and reliable on-wafer FAHLP station was achieved, despite the range of optical facilities available.

The device used for the electroluminescence measurements was a UMS 8 x 125µm GaN HFET on a silicon carbide substrate, as shown in fig. 1, the drain bias voltage was set at 28V.

The Measurement Systems

A proven Large Signal (LSNA) system architecture based on a VTD SWAP-X402 receiver was used for this study [5]. An external modulator can be used for pulsing the RF and DC drain bias if required, with high speed RF switches to modulate the RF while a high side FET switch modulates the drain DC bias [2]. The RF and drain bias can be independently switched between pulse and CW, enabling three different measurement conditions without making any changes to the sampling regime, therefore any measured changes can safely be ascribed to the device under test. The RF and DC switches also function as circuit breakers in the event of an overload, this permits the full range of circuit topologies such as A,B,AB,C,F,F^{-1},J and continuous F be explored in both pulse and CW modes, with minimal risk to the measuring equipment, an important point in view of the cost of wafer probes.

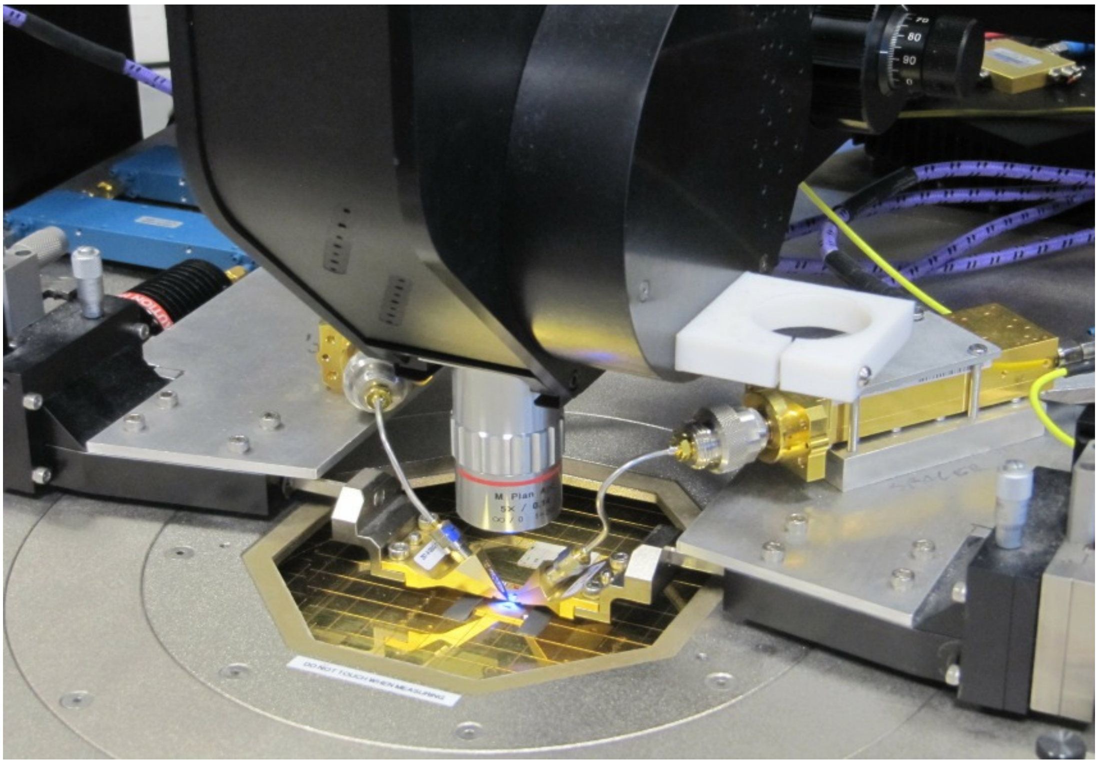

Figure 2 A Cascade wafer probe station.

A typical wafer probe station has a large degree of movement built into all of the main features, the top-side optical microscope used for positioning, the RF wafer probes and the sample under test can all be moved, the X-Y table used for the latter normally precludes any backside access and the whole structure is complex. The Cascade Summit 1200 pictured above (fig. 2) incorporates Z axis and Theta (rotation) as well. In fact much of this complexity is redundant, since the positioning microscope, the wafer probes and whatever instrument is accessing the backside must all address the same place within a fraction of a millimetre. By fixing the positioning microscope we can define a point of measurement which everything else can be adjusted to and then left in place, only the various devices under test need to move significantly. The concept makes it easier to align a backside fixed magnification microscope, as this can be done coarsely by removing the wafer and aligning the centre of the objective with the wafer probe tips, as seen through the optical topside microscope. It is then a simple matter to finalize the alignment directly. In a similar fashion the optical fibre for the spectrometer can be aligned, in this case fine alignment is assisted by attaching an LED to the other end of the cable, in place of the spectrometer, so that the device under test appears clearly back-lit by the fibre, allowing the fibre to be centred exactly beneath the device channel.

The new station (fig. 3) was made from a 19" rack frame, with a 1/4" steel plate attached across the top by stiffening angle sections, with cross bracing added to stiffen the frame itself. A 1 1/2" diameter hole through the center of the plate defines the measurement area. The wafer probe positioners are mounted on raised and undercut blocks, enabling any part of a 4" wafer to be placed under the probe tips. The RF measurement couplers are securely attached to the deck of the probe station, and attached to the wafer probes by short flexible cables, forming a consistent calibrated assembly. The cables to the rest of the load pull system were fed out the rear, so as to facilitate the placing of a blackout cover over the measurement area.

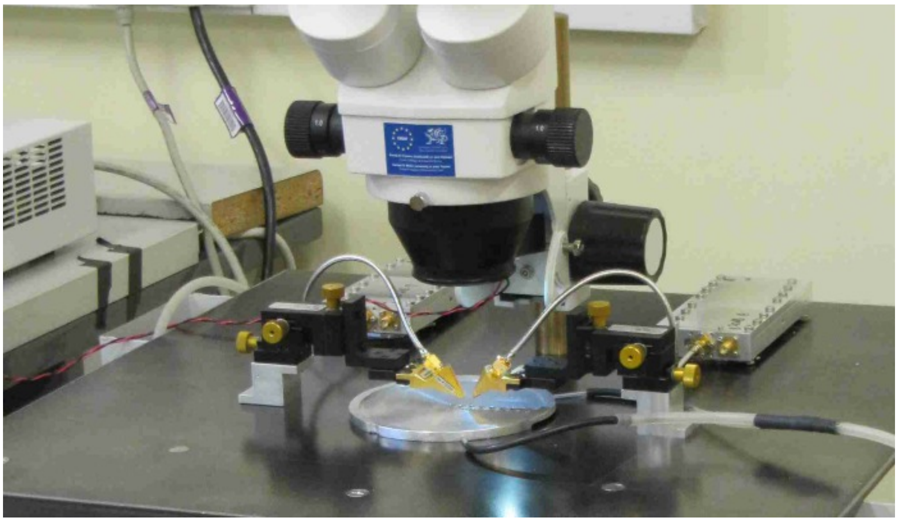

Figure 3 The RF deck of the new wafer probe station

A custom vacuum chuck was fabricated from aluminum, to support the wafer and help to dissipate the thermal load. In addition to the usual vacuum ports to hold the wafer to the chuck and the chuck to the deck, a pattern of 5mm holes through the chuck was arranged so as to permit any part of the wafer to be placed directly over a hole, by rotating the chuck relative to the wafer and deck.

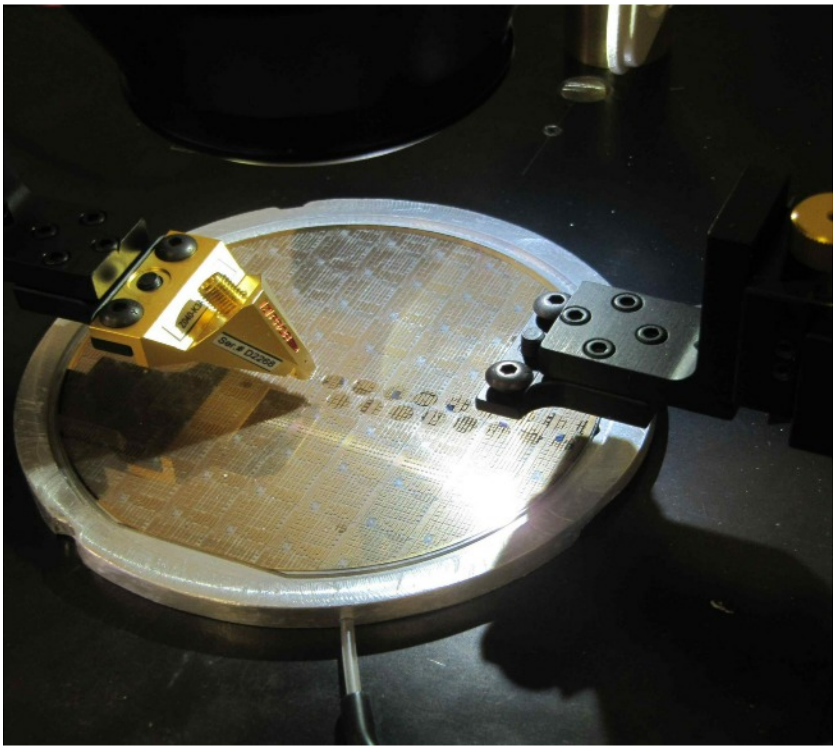

Figure 4 The vacuum chuck with holes giving rear access.

Electroluminescence Measurements

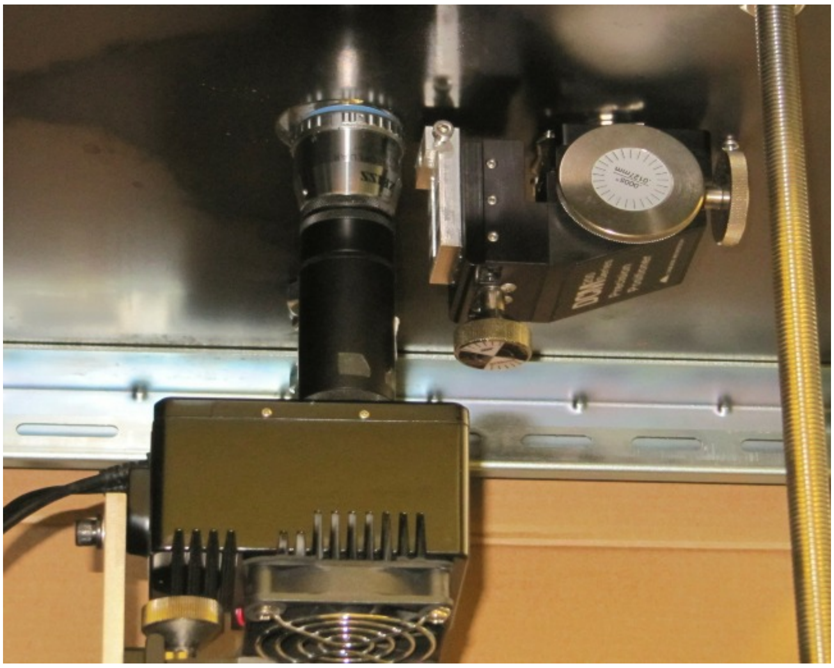

Fig. 5 The ultra-lowlight camera in position under the RF deck.

There are two parts to the Hot Electron EL measurements, microscopy and spectroscopy, to determine intensity and spectral distribution. For the former, a Peltier cooled low light astronomical camera fitted with a x50 LWD objective lens was mounted on an XYZ micro-positioner, supported on a platform suspended beneath the deck. Initial focusing and alignment can be performed with the device powered down and with the topside light on, however since the EL is generated in the channel, beneath the device electrodes, a fine adjustment will be needed to optimize the image. Figure 6 shows a typical image in negative monochrome. Image analysis software can be used to compare intensities in differing operational conditions. It is also possible to identify damaged areas forming “hot spots” along the channel, in case for example of OFF-state stress [6].

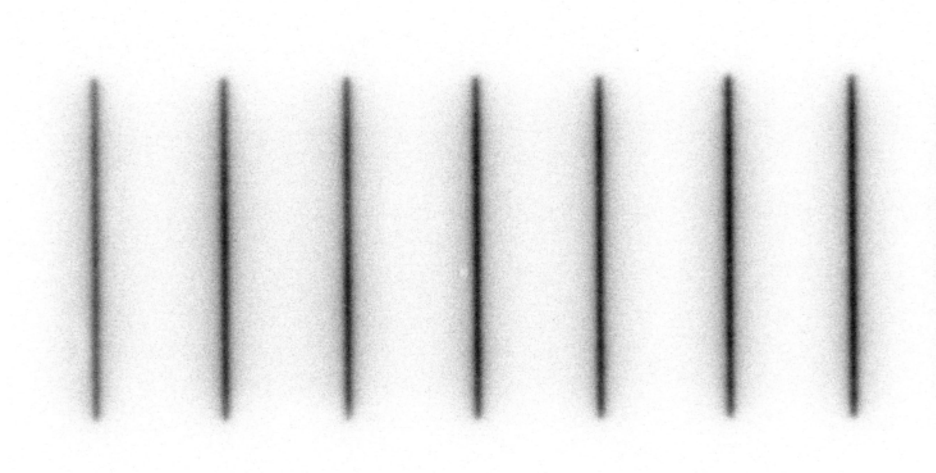

Fig. 6 Electroluminescence from a 8x125 UMS GaN die (monochrome, negative).

Once the intensity has been recorded for the range of conditions being studied then the microscope is replaced by the spectrometer, an Oceanoptics QEpro unit with a Peltier cooled sensor. The light is directed into the spectrometer by a broad spectrum fiber optic cable, the open end of this is attached to a micro-positioner on the underside of the probe station deck, by observing through the wafer the active area of the fiber can be centralized beneath the device under test.

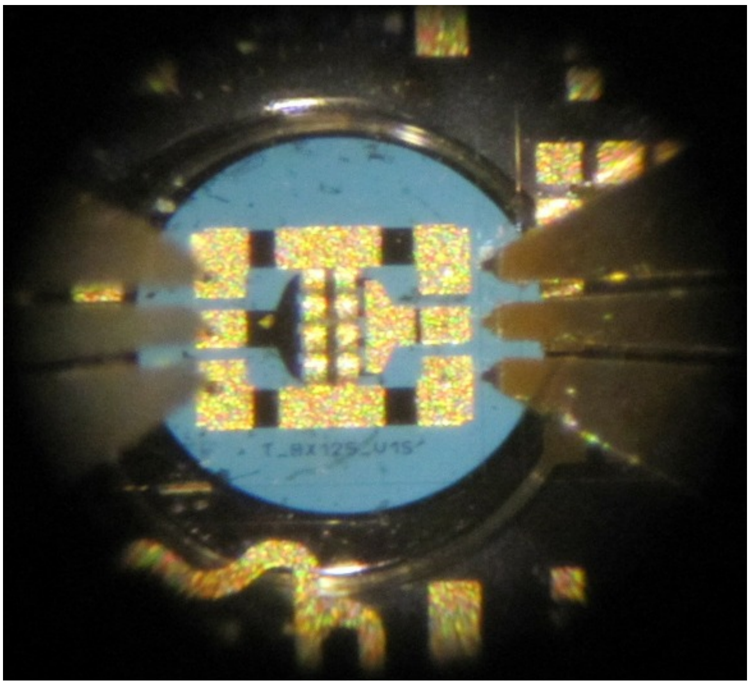

Fig. 7 The RF device centred over the fibre optic cable

Once the cable is aligned then the series of conditions measured with the camera can be repeated and the spectral distribution recorded for each case (fig. 8). After calibrating the response of the system with an Oceanoptics lamp standard, the real spectral distribution of the light emitted from the device can be extracted (fig. 8). The fitting of the spectra with an exponential decay form [4] can give an estimation of the electron temperature related to the carriers involved in the transport and EL emission during RF operation.

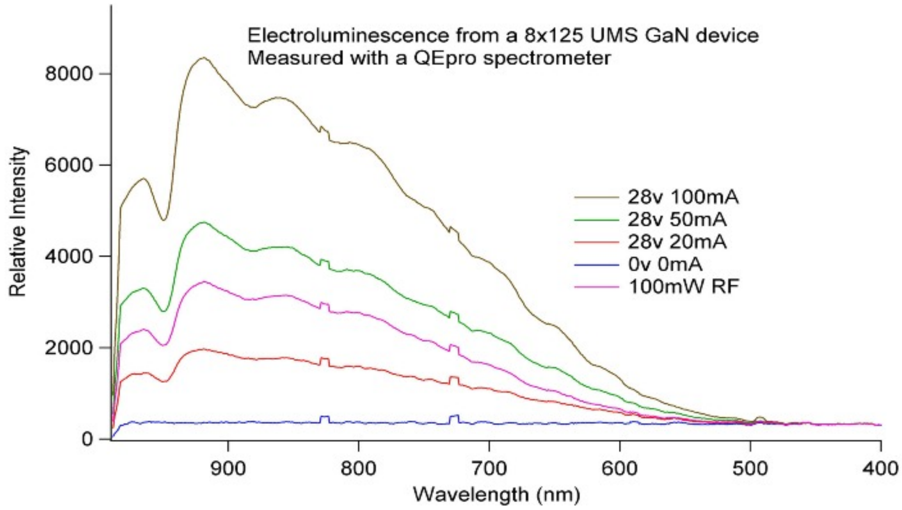

Fig. 8 The electro-luminescence spectra under DC and low power RF

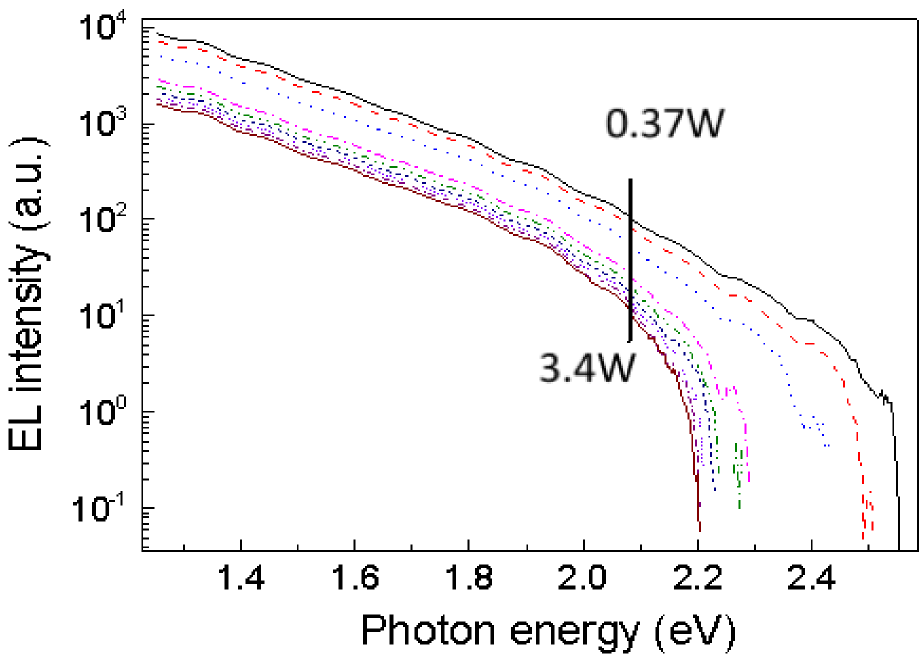

Fig. 9 Corrected distribution under Class B operation for a range of RF power levels.

As shown in the past, the EL emission analysis contains important information linked to the possible degradation due to hot electrons. Thanks to this analysis it has been pointed out how average hot electron effects in AlGaN/GaN during RF stress may actually not have a major role when compared to a DC stress on the same load line [4]. This has been confirmed by both EL intensity and and electron temperature measurements for Class B and Class J modes of operation [7]. Highest EL intensity occurs when the current and voltage are both high, at the center of the load line. Under RF operation more time is spent near one or other of the axis while the signal sweeps over the load line, hence EL intensity is reduced as power increases (fig. 9). Instantaneous degradation effects can however take place at high voltage points during the sweeping and not be observed.

Photosensitivity Measurements

In "Advanced RF IV Waveform Engineering Tool for use in device technology optimization: RF Pulsed Fully Active Harmonic Load Pull with Synchronized 3eV Laser" [4] the effect of short wavelength light on knee walkout in GaN devices was described, see fig. 10, however this was purely qualitative, no attempt was made to assess the intensity of the light, the apparatus described here provides a convenient way to deliver a consistent and quantified amount of light.

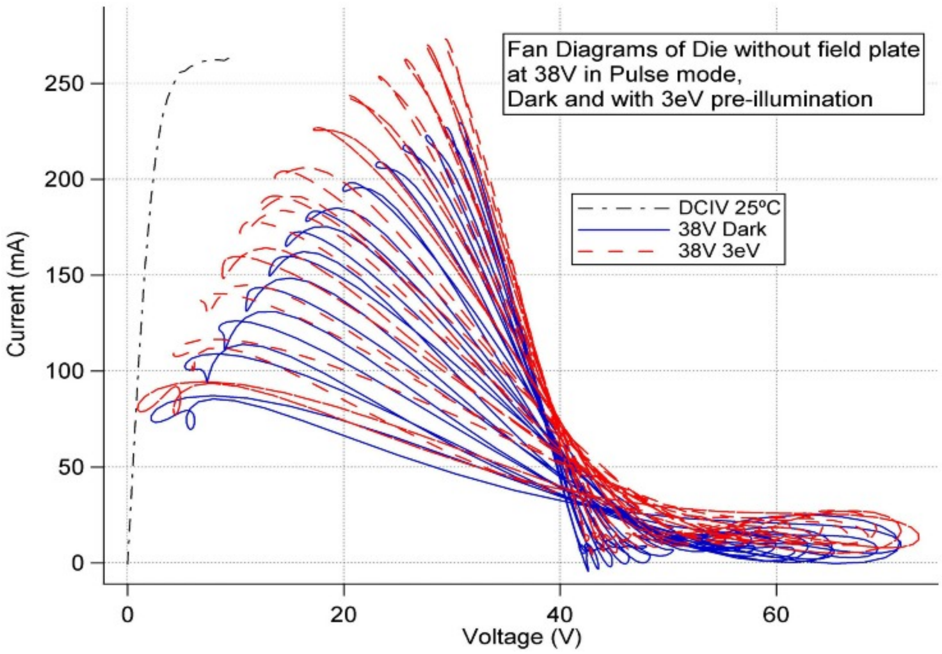

Figure 10 The effect of 3eV laser light on the load-lines of a Win GaN device.

In the earlier work the output from a 3eV (405nm) laser diode was concentrated by optics onto the top surface of the die, while effective this does not permit comparisons between light sources of different wavelengths. With this apparatus it is practical to detach the optical fiber from the probe station and connect that end to the spectrometer, so that an LED attached to the other end can be characterized, intensity vs. current. Once the cable is reattached beneath the die the effect upon the loadlines across the current range can easily be measured, this process can then be repeated for different sources. In figure 11 below we can see the effect of equal intensities of blue (480nm) and violet (395nm) light on the same Win Semiconductor Corp 2 x 125 devices used previously, with the fundamental, second harmonic and third harmonic loads all set to a reflection coefficient of 0.5, and a duty cycle of 10% (it should be noted that these are prototype devices, the performance is not representative of current production parts). The blue light has a slight effect, while the violet has a pronounced effect, clearly the energy level of the photons is a significant factor in the photosensitivity.

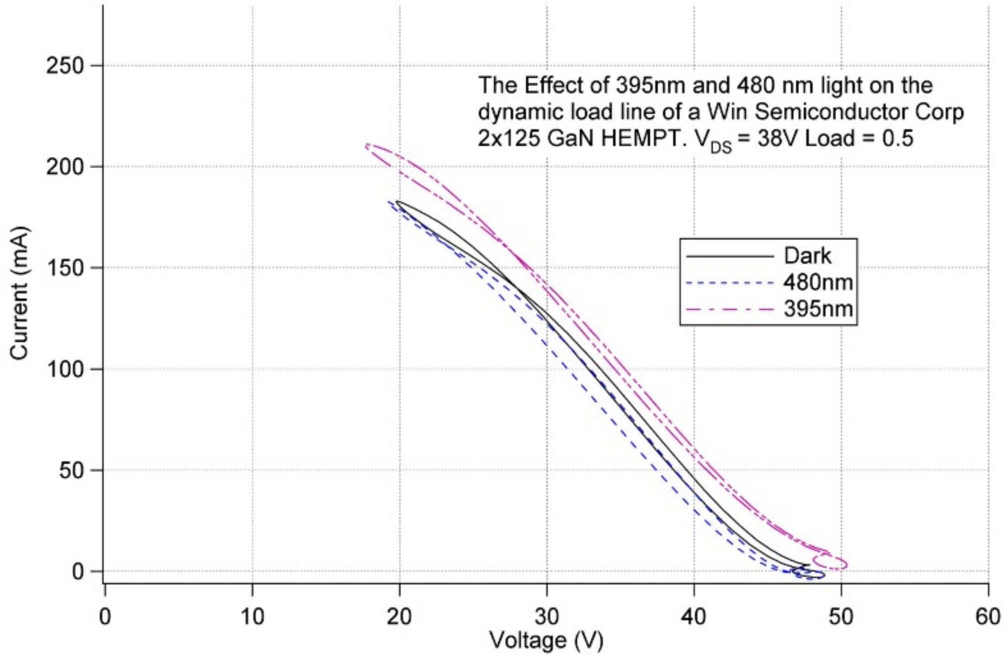

Figure 11 The differing effects of 395nm and 480nm illumination

The effect of intensity can also be observed , figure 12 shows that the rate of change of the load-line with regard to intensity is rapidly diminishing at the upper end of the experimental range, indicating that the apparatus is adequate for the task.

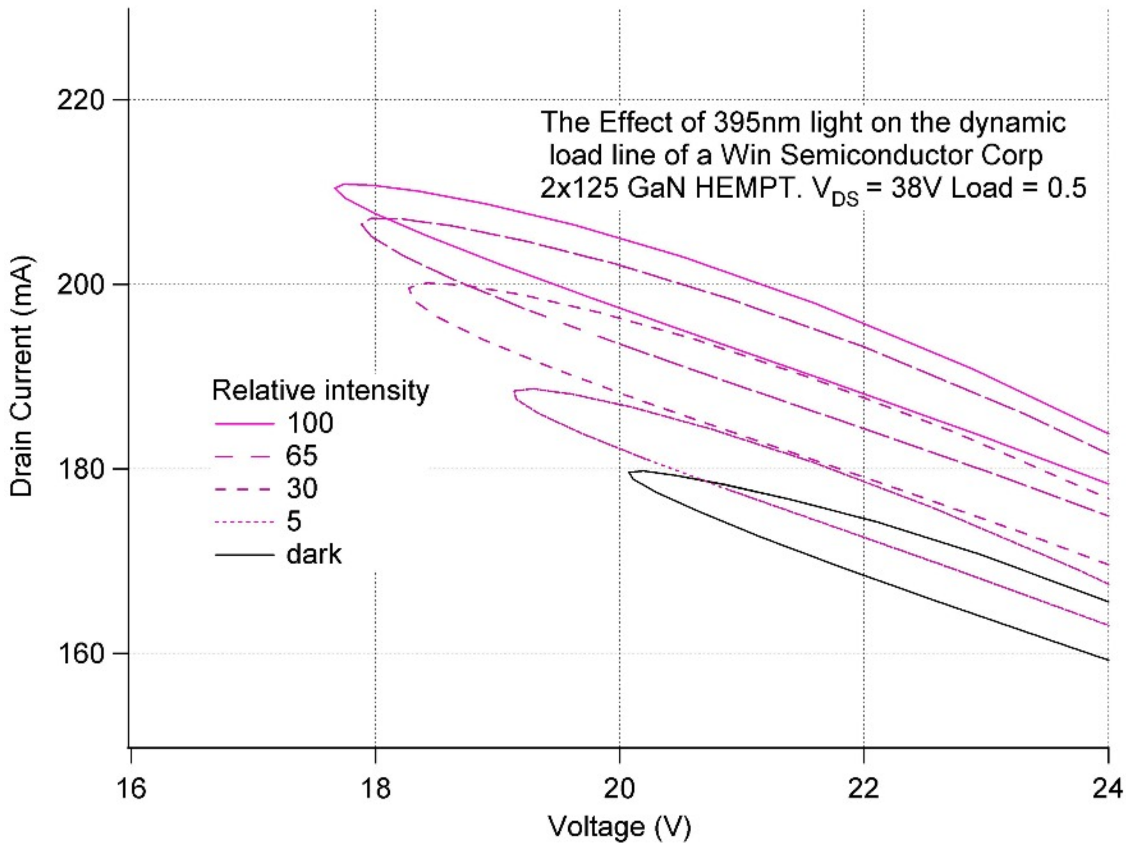

Figure 12 The effect of 395nm intensity on the load-lines.

Conclusion

It has been demonstrated that accurate waveform engineering techniques can be used to comprehensively exercise an on wafer device while simultaneously measuring Hot Electron Electroluminescence, or conversely to quantify the effect of illumination on device RF behavior, and so help to diagnose process problems when developing new materials.

Acknowledgement

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