nent before the Cu-TaN interface is believed to be caused by the non-uniformity of lateral or layer-by-layer oxidation of Cu, which is not well understood and needs further investigation. The oxidation of the Cu surface occurs because of the high annealing temperatures involved and the failure to eliminate completely the oxygen content in the ambient atmosphere. It is also important to note that the SIMS results are compromised by the extremely rough surface caused by grain growth.

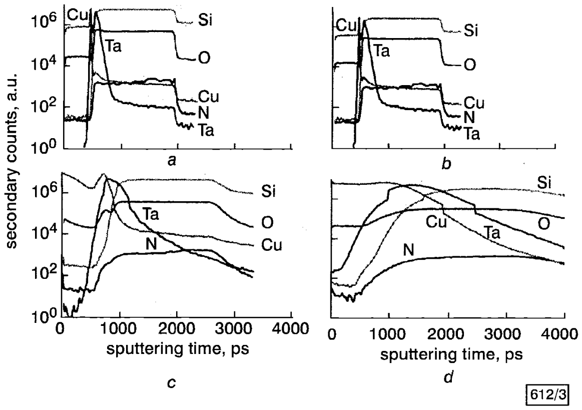

Fig. 3 *SIMS depth profiles of IMP Cu (200nm)/IMP TaN (30nm)/ PECVD SiO_2 (500nm)/Si samples*

a As-deposited
b 400°C ½ hr
c 600°C ½ hr
d 800°C ½ hr

Conclusion: A 30nm thick TaN diffusion barrier has been proven to be versatile enough to sustain an annealing temperature to around 700–800°C, making it an excellent choice as a barrier for copper metallisation.

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Investigation of traps producing current collapse in AlGaN/GaN high electron mobility transistors

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Current collapse in AlGaN/GaN HEMTs has been investigated using photo-ionisation spectroscopy techniques to probe the spatial origins of the traps producing this effect. The results indicate that the responsible traps reside in the high-resistivity GaN buffer layer and are identical to those traps causing current collapse in GaN MESFETs.

Introduction: An important problem facing nitride-based high-power microwave electronics is the presence of trapping centres resulting from deep defects and/or impurities in the materials. Current collapse is a trap-related phenomenon that has been observed to produce a significant reduction in the drain current of nitride-based devices [1 – 4]. This effect occurs when a high drain-source voltage is applied to a field effect transistor (FET), and hot channel carriers are injected into regions adjacent to the active channel, where they are then trapped at deep defect sites. When the high voltage is removed, the carriers remain trapped. This reduces the drain current and hence the output power. The severity of this effect can vary widely between individual wafers. Thus, while excellent device properties can be obtained, an important reproducibility problem remains.

For the GaN metal-semiconductor FET (MESFET), we have recently shown [1, 3] that the responsible traps reside in the high-resistivity (HR) GaN buffer layer. However, for high-electron mobility transistors (HEMTs), it is also possible for the traps to originate at the interface, in the AlGaN layer, or at the surface. In this Letter, we investigate the location of these traps by carrying out photoionisation spectroscopy measurements on devices grown by organometallic chemical vapour deposition (OMCVD) and by molecular beam epitaxy (MBE).

Photoionisation spectroscopy: The trapped carriers give rise to a reduced drain current, and a large electric field [4] results from the net transfer of charge. Light above the absorption threshold photoionises the carriers, emptying the traps. In the HEMT structure, as a result of the field, the photoionised carriers rapidly drift back to the two-dimensional electron gas (2DEG), thus restoring the drain current. The wavelength dependence of this current increase reflects the photoionisation cross-section (absorption coefficient per absorbing centre) of the trap. This not only provides information about the depth of the trap relative to the bands, but also serves as a signature of the trap. Owing to the nature of the measurement, the technique is sensitive to only those traps that contribute to the current collapse.

The experiment is carried out by performing two I-V measurements in sequence. After illumination with a blue GaN LED to empty all of the traps, the first I-V measurement is carried out to relatively high voltage, in order to produce the current collapse. After a timed delay, a second I-V is obtained, and the drain current at small drain voltage is measured. This process is carried out with and without light illumination, and the results are compared. In the dark, all of the traps remain filled, while under light illumination, some of the traps are emptied and the drain current is partially restored. We define [3, 4] the optical response function $S(h\nu)$ as the fraction of the filled traps that have been emptied per incident photon, given by the ratio of the drain current increase to the drain current in the dark, and divided by the total number of incident photons. When the drain current is measured in the linear portion of the I-V curve and the light illumination is low, $S(h\nu)$ has been shown [4] to be proportional to the photoionisation cross-section of the trap.

Results: In this Letter, we compare the results for four devices (gate widths in the range 75–300μm): (1) an OMCVD-grown GaN MESFET, described in [1, 3]; (2) an MBE GaN MESFET grown on top of an HR OMCVD/sapphire GaN template; and (3) two AlGaN/GaN HEMT devices (labelled i and ii) grown by OMCVD on sapphire. Typical I-V measurements for these devices are shown for V_{GS} = 0V in Fig. 1. The initial I-V for each device is given by the solid curve, while the dashed curve represents the second I-V taken in the dark. The latter corresponds to the fully collapsed I-V, where all of the traps have been filled. I-Vs taken under light illumination will appear somewhere in between the solid and dashed curves, as reflected by the amount of drain current recovery, which depends upon the amount of light applied.

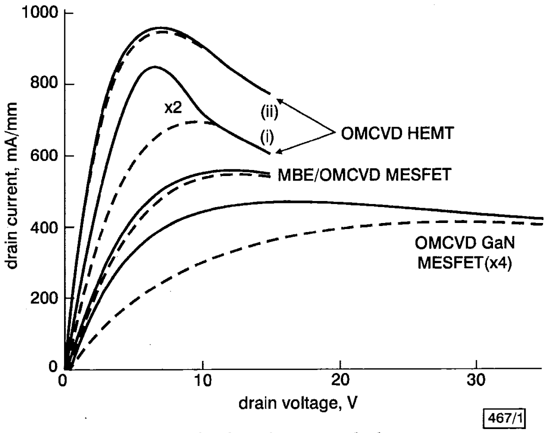

Fig. 1 *Typical I-V curves for four devices studied*

Collapsed I-Vs are shown by dashed curves

The two OMCVD HEMTs in Fig. 1 ((i) and (ii)) are representative of the broad range of behaviour that we have observed from these devices, which were fabricated on materials grown under varied process conditions. The collapse in this particular MBE-grown MESFET appears much smaller than that seen in the OMCVD-grown MESFET.

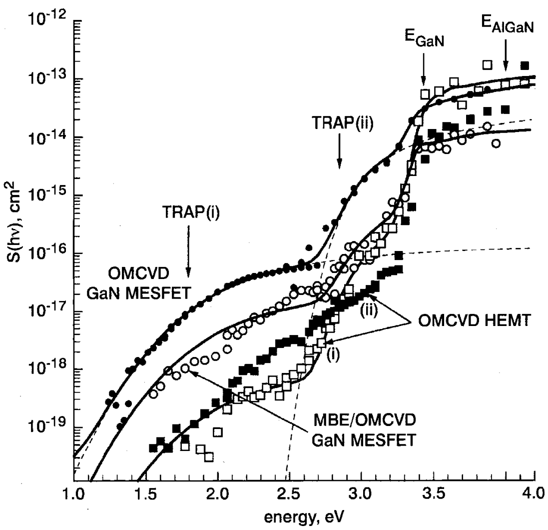

Fig. 2 *Photoionisation spectra for four devices studied*

The two HEMT devices are labelled (i), (ii) to correspond to the I-V curves in Fig. 1

The photoionisation spectra of these devices, *S*(*hν*), are shown in Fig. 2. The spectrum of the OMCVD MESFET was discussed in [3], and appears as the solid circles. The two broad absorptions, associated with photoionisation at two distinct traps (labelled TRAP(i) and TRAP(ii)), were identified [3] with traps in the HR GaN buffer layer. The absorptions could only be fitted (dashed lines) assuming large lattice relaxation [5], and yielded absorption thresholds at 1.8 and 2.85eV. This identifies TRAP(i) as a mid-gap level and TRAP(ii) as a very deep acceptor/electron trap. The solid lines in the Figure are linear combinations of the fitted absorptions. The spectra of the OMCVD HEMTs (solid and open squares) and the MBE-on-OMCVD MESFET (open circles) exhibit the same spectral features as those of the OMCVD GaN MESFET, suggesting that they are due to the same traps. In addition to the trap-related absorptions, all four spectra show a clear increase at the bandgap of GaN, corresponding to the optical excitation of free carriers. This increase is smaller in the case of the MESFETs because much of the above-gap light is absorbed in the 200nm GaN layer that lies above the HR GaN. This, coupled with the similarity of the spectra to that of the OMCVD GaN MESFET, clearly indicates that current collapse in the HEMT devices occurs in the HR GaN layer, and that the responsible traps are identical to those in the OMCVD MESFET.

The collapse in the MBE device could be due to similar traps associated with the growth. Alternatively, if these traps are associated with dislocations, it is possible that current collapse in the MBE-grown device results from dislocations that propagate into the MBE layer from the OMCVD template. Detailed studies of MBE-grown materials are needed to better characterise the role of current collapse in these devices.

Conclusions: Current collapse in OMCVD-grown HEMTs has been shown to result from the same traps that produce current collapse in OMCVD GaN MESFETs. As in the MESFETs, these traps are located in the HR GaN buffer layer.

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Constrained VQ codebook design for noisy channels

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A codebook design approach for constrained vector quantisation using the Hadamard transform of channel transition probabilities is proposed. It is examined for quantisation of Gauss-Markov sources over channels with memory and compared with the generalised Lloyd algorithm.

Introduction: Vector quantisation (VQ) is an efficient speech and image compression method. However, transmitting VQ data over noisy channels changes the index bits and consequently leads to severe distortions in the reconstructed output. Forward error control could be used to protect VQ data, but it would be more efficient to design a VQ codebook with inherent good channel robustness properties. Among many design approaches to be con-