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# Source resistance reduction of AlGaN/GaN HFET using novel superlattice cap layer

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## 1. Introduction

AlGaN/GaN HFETs are drawing considerable attention not only as high power RF devices [1] but also as small signal amplifiers or as RF switches [2]. One emerging issue of these devices is their high parasitic, i.e. source and ohmic contact, resistances resulting in seemingly low transconductance. One promising approach to overcome this problem is to cap the AlGaN barrier layer with a highly doped n-type GaN layer. Although a remarkable improvement in transconductance with this technique has been reported [3], mechanism leading to such a performance is not clear and a definite methodology to reduce the parasitic resistance in AlGaN/GaN HFETs has not been established yet. In this respect, an AlGaN/GaN superlattice (SL) capped structure is another very attractive technique in which dramatic increase of electron density is expected owing to the existence of the multiple AlGaN/GaN interfaces in the SL cap. In this work, we have demonstrated for the first time, an excellent performance of the SL cap which significantly reduced the parasitic effects. Correspondingly, we confirm increases of the drain current and the transconductance with the SL cap by 13%. Detailed calculation results show that the primary functions of the SL cap are two folds: (1) Lowering of the effective barrier height seen between the contact metal and the 2 dimensional electron gas (2DEG). (2) Lowering of the sheet resistance due to the increased charge concentration within the SL layer. It is noted that a remarkable, i.e. 75%, reduction of source resistance is achieved with this technique compared with the GaN cap method.

## 2. Principle of source resistance reduction by the SL cap

A basic structure of SL capped HFET is illustrated in Fig.1. The sourve and drain ohmic electrodes are formed on the SL cap layer while the gate electrode is formed on the original HFET barrier layer surface. Because of the existence of the multiple AlGaN/GaN interfaces, electron density in the SL cap is expected to be high. In Fig.2, conduction band energy levels of an SL (solid line) and a GaN (dotted line) cap structures calculated by a self-consistent Poisson-Schrödinger equation solver. It is clearly seen that the effective potential barrier ($\phi_{AlGaN}$) between the surface Fermi level and the top of the conduction band of the AlGaN barrier is lowered by 0.5 eV for the SL cap layer.

## 3. Experimental Procedure

The layer used in this study was grown by metal-organic chemical vapor deposition (MOCVD). The structure of the SL capped AlGaN/GaN HFETs consisted of $n^+$-GaN/ n-AlGaN/n-GaN SL/n-ALGaN/i-GaN/AlN buffer/Sapphire substrate as illustrated in Fig.1. The SL layers were doped with Si and the concentration was $1\times10^{19}$ cm$^{-3}$. The total thickness of the SL layers was constant, i.e. 50nm. Several types of the SL caps were prepared by the ratio of thicknesses of AlGaN and GaN layers. As a reference, we fabricated an n-GaN capped HFET.

Source/drain and gate electrodes were Ti/Al and PdSi/Pd/Au, respectively. Gate electrodes with 1 μm length were formed on the AlGaN barrier layer after recessing the cap layers.

The source resistance and the ohmic contact resistance of the fabricated HFETs were measured by the Yang-Long [4] and the transmission line model methods, respectively.

## 4. Results and Discussion

In Fig.3, transmission electron microscope (TEM) image of an SL cap is shown. Excellent quality of the layer is confirmed by the sharp AlGaN/GaN interfaces, by thickness uniformity of each layer, and by high crystallinity. Figure 4 shows DC characteristics ($I_D$-$V_D$ curves) of the fabricated HFETs with the SL and the GaN caps. It is obvious that the drain current of the SL cap HFET increased by about 13% as compared to that of the GaN cap HFET. Also, the low field on state resistance of the SL cap HFET is lower than that of the GaN cap device as indicated by the large difference in the slopes of the two $I_D$ curves. Correspondingly, transconductance in saturation regime of the SL cap HFET also improved by 20% as shown in Fig. 5.

The measured source ($R_s$) and contact ($\rho_c$) resistances of each device are tabulated in Table 1. It is interesting to observe that both $\rho_c$ and $R_s$ are strong functions of the AlGaN/GaN thickness ratio within the SL layer: With the increase of the relative AlGaN thickness, the $R_s$ and $\rho_c$ were found to be minimized to 1.0 Ω·mm and $1.1\times10^{-5}$ Ω·cm$^2$. The electrical properties of the capped HFET structure can be analyzed by the Feurer's 2-layer model shown in Fig.6 [5]. With this model, the total resistance between points A and B can be analytically expressed. Since the sheet resistances of the cap ($r_{s1}$) and 2DEG layers ($r_{s2}$), the contact resistance between source and the cap ($R_{c1}$) and the total resistance between point A and B ($\rho_c$) can be determined experimentally, the only unknown resistance of $\rho_{12}$ is uniquely determined. In Table 1, thus obtained $\rho_{12}$ are tabulated. It is interesting to observe that $\rho_{12}$ and $R_s$ have strong correlation. Furthermore, in Fig.7, we plot the effective barrier height, $\phi_{AlGaN}$ calculated by the above-described calculation shown in Fig.2 and the extracted $\rho_{12}$ of each sample. It is confirmed that the two quantities are linearly proportional suggesting that the effective barrier lowering is indeed due to the effective tunneling barrier decrease in addition to the sheet resistance lowering.

## 5. Conclusion

We have demonstrated a new method to reduce the parasitic resistances of AlGaN/GaN HFETs by the SL cap structure for the first time. It was shown that the SL cap is capable of lowering of the effective barrier height seen from the contact metal to 2DEGs. It was confirmed that the drain current and the transconductance with the SL cap were increased by 13% and 20%, respectively. We emphasize that the SL cap is indeed a versatile tool to engineer the parasitic effect of the AlGaN/GaN HFETs.


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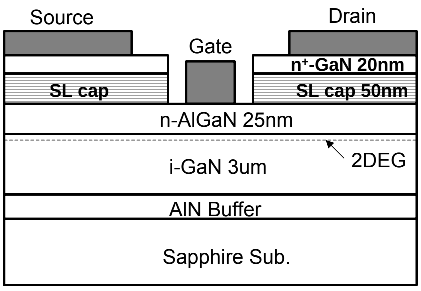


Fig. 1 A cross sectional view of a fabricated SL cap HFET.

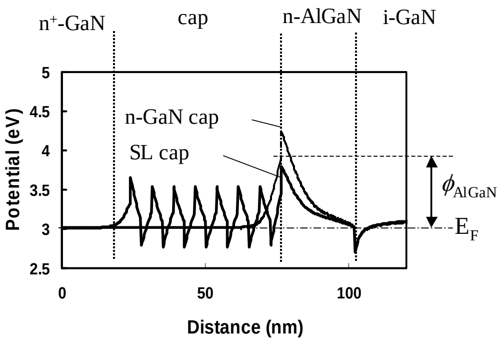


Fig 2. Calculated conduction band profiles of an SL (solid line) and a GaN (dotted line) cap HFETs.

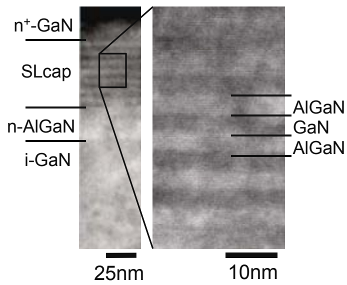


Fig.3 Transmission electron microscope images of an SL cap.

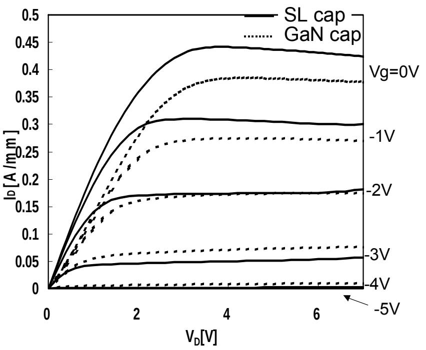


Fig.4 Drain characteristics of fabricated SL and GaN cap HFETs.

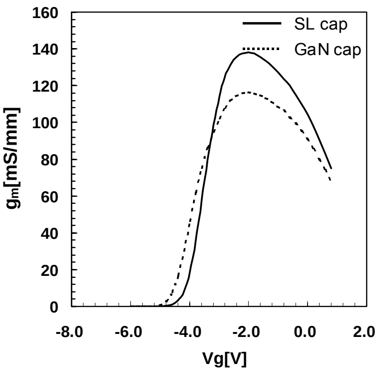


Fig.5 Transconductance vs. gate voltage characteristics of fabricated SL and GaN cap HFETs. The $V_D$ was applied to 5V.

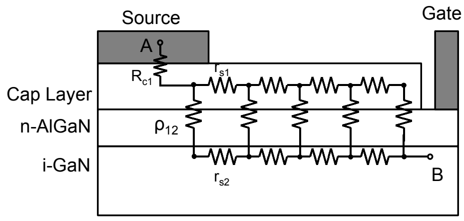


Fig.6 An equivalent circuit model [5] of the cap and the channel regions of an HFET.

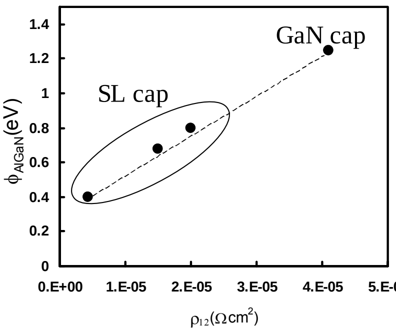


Fig.7 A correlation diagram between a tunneling resistance $\rho_{12}$ and the calculated effective barrier height $\phi_{AlGaN}$.

Table.1 Measured source ($R_s$), contact ($\rho_c$) and sheet ($R_{sh}$) resistances of the investigated devices. Extracted tunneling resistance $\rho_{12}$ and calculated effective barrier height $\phi_{AlGaN}$ are also shown.

| | AlGaN/GaN thickness | $R_{sh}$ (Ω/ ) | $\phi_{AlGaN}$ (eV) | $R_s$ (Ωmm) | $\rho_c$ ($\Omega cm^2$) | $\rho_{12}$ ($\Omega cm^2$) |
|---|---|---|---|---|---|---|
| SL cap | A: 3.5 / 3.5nm | 140 | 0.8 | 2.7 | $4.5\times10^{-5}$ | $2.0\times10^{-5}$ |
| | B: 4.6 / 2.3nm | 170 | 0.7 | 2.0 | $3.7\times10^{-5}$ | $1.5\times10^{-5}$ |
| | C: 5.6 / 1.4nm | 180 | 0.4 | 1.0 | $1.1\times10^{-5}$ | $4.3\times10^{-6}$ |
| Conventional GaN cap | | 130 | 1.3 | 3.9 | $1.4\times10^{-4}$ | $4.1\times10^{-5}$ |