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Dynamic performance enhancement in Ti/Au ohmic contacts on β-Ga_2O_3-on-SiC substrates: evidence from pulsed measurements

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Titanium/Gold (Ti/Au) metals have been widely employed as ohmic metal contacts on n^+ Ga_2O_3, exhibiting the specific contact resistance (ρ_c) of 10^{-5}–10^{-6} $\Omega\cdot cm^2$ [1]. But previous studies have revealed the presence of a defective Ga_2O_3 layer and reactive Ti-Ga_2O_3 layer at the annealed Ti/Ga_2O_3 interface. Such an interfacial layer can affect the performance of ohmic contact, which may become more pronounced in power devices subjected to electrical stress and high-frequency operations. However, there have been no reports on the impact of bias stress effects and dynamic degradation of Ti/Au ohmic contacts on n^+ Ga_2O_3.

In this study, we have presented the first characterization of the dynamic performance of Ti/Au ohmic contacts on β-Ga_2O_3 and showcased a reduction in ρ_c during pulsed measurements. Moreover, the mechanism responsible for the dynamic performance of Ti/Au ohmic contacts on n-Ga_2O_3 is elucidated through the theoretical calculations.

Figure 1(a) shows a cross-sectional schematic of the Ti/Au contacts on GaOSiC. To introduce n^+-type doping into the Ga_2O_3, a Si^+ implant with an energy of 25 keV and a total 1×10^{15} cm^{-3} dosage was performed. A thermal annealing process at 1100°C was carried out for dopant activation. To fabricate transmission line method (TLM) structures, mesa isolation was formed through dry etching, followed by Ti/Au layers deposition using electron beam evaporation with a lift-off process. Finally, an annealing process at 470°C in nitrogen for one minute, which is widely adopted to establish superior Ti/Au ohmic contacts on n^+ Ga_2O_3 [1], was carried out in this study.

The schematic of the pulsed voltage waveforms for dynamic *I*-*V* measurement is illustrated in Figure 1(b). The base voltage $V_{\rm Base}$ corresponds to the bias stress voltage applied to the ohmic contact, and the pulse voltage $V_{\rm Pulse}$ is aimed at recording the current values. During one pulse period ($T_{\text{P-}p}$), the ohmic contact is initially stressed at $V_{\rm Base}$ and then transitions to $V_{\rm Pulse}$. The currents are recorded by the $V_{\rm Pulse}$ at the measurement points during the pulse width ($T_{\text{P-}w}$). $T_{\text{P-}w}$ is set to 500 μs for measuring current values, and the $T_{\text{P-}p}$ is set to 500 ms to maximize the effect of bias stress voltage $V_{\rm Base}$.

Figure 1(c) displays the *I*-*V* characteristics obtained by applying a DC voltage across two adjacent Ti/Au/n^+ Ga_2O_3 contacts before applying bias voltage stress. In Figure 1(d), a linear decrease in the total resistance ($R_{\rm T}$) between the contacts is demonstrated as the d decreases, by which, the contact resistance ($R_{\rm c}$) and ρ_c can be extracted. For comparison, Figures 1(e) and (f) exhibit the DC electrical characteristics of the devices after undergoing a series of electrical stress tests. Notably, we observed a significant decrease in $R_{\rm c}$ after applying the stress series, resulting in a 68% reduction of ρ_c, from 1.8×10^{-4} to 5.6×10^{-5} $\Omega\cdot cm^2$.

Dynamic bias voltage stresses were applied by varying $V_{\rm Base}$ from 5 to 35 V, and measured $V_{\rm Pulse}$ was swept from −1 to 1 V for all base voltage conditions. Figure 1(g) depicts the dynamic *I*-$V_{\rm Pulse}$ performance of the ohmic contacts with different d and varying $V_{\rm Base}$. From Figure 1(h), it is observed that Ti/Au ohmic contacts on n^+ Ga_2O_3 with different d all exhibit a monotonously decreased $R_{\rm T}$ under bias voltage stress with $V_{\rm Base}$ increasing from 5 to 35 V. As $V_{\rm Base}$ increases, the dynamic $R_{\rm T}$ for different spacing d exhibit a similar decrease, indicating that the decrease in $R_{\rm T}$ is not due to the temperature rise caused by the high

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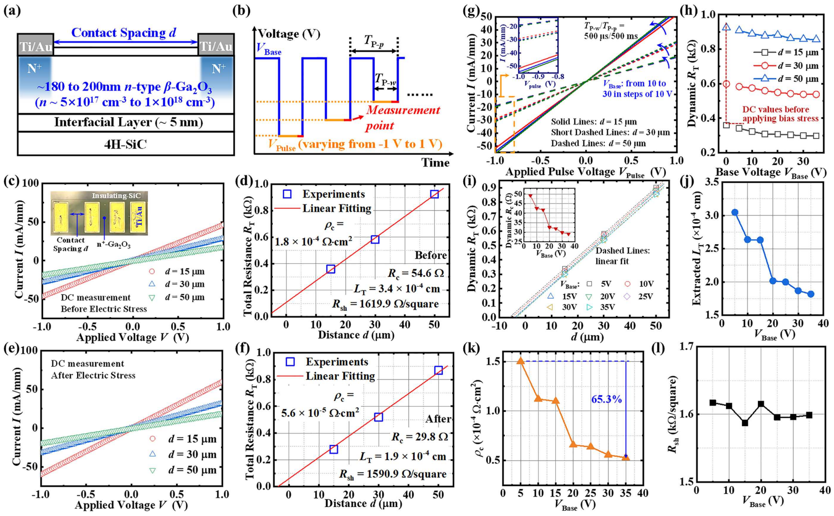

Figure 1 (Color online) (a) A cross-sectional schematic illustrating the Ti/Au contacts on GaOSiC. (b) Illustrative pulsed voltage waveforms for dynamic *I*-*V* measurement. (c) DC *I*-*V* curves, measured between Ti/Au contacts with varying *d*, formed on n^+ Ga_2O_3 before applying the bias voltage stress. An inset provides an optical micrograph of the TLM structure. (d) A plot depicting the R_T between Ti/Au contacts as a function of *d*. (e) The devices' DC *I*-*V* and (f) R_T-*d* curves after experiencing electric stress. (g) Pulsed measurement of the Ti/Au ohmic contacts on GaOSiC with varying V_{Base}. (h) The V_{Base} dependence of measured dynamic R_T for the stressed ohmic contacts with different *d* values. (i) The measured dynamic R_T between Ti/Au contacts as a function of *d* with varying V_{Base}. The extracted (j) L_T, (k) ρ_c, and (l) R_{sh} for the contacts under dynamic bias voltage stress with different V_{Base}.

voltage and high current during the pulse measurement process, since the thermal effects caused by high current would become more severe with decreasing *d*.

Figure 1(i) plots the relationship between dynamic R_T and *d* of the TLM structure under different V_{Base} values. Symbols represent the measured data, and the dashed lines indicate the linear fitting lines. The linear relationship between the spacing *d* and dynamic R_T validates the accuracy of the extracted R_c. In Figure 1(j), it can be observed that the extracted transfer length (L_T) decreases with increased V_{Base}. The decrease in L_T signifies the required ohmic contact length through which the current flows in the TLM structure become smaller. This reduction in L_T can be attributed to an increase in current within Ga_2O_3 and a decrease in the effective potential barrier ($\phi_{b,eff}$) in the local region of the ohmic contact. Figure 1(k) demonstrates the calculated ρ_c also exhibits a consistent downward trend as V_{Base} increases. Notably, a significant decrease of 65% in dynamic ρ_c was observed after pulse measurement with a V_{Base} of 35 V, resulting in a higher performance ohmic contact. The variation in ρ_c is a comprehensive performance metric influenced by both R_c and sheet resistance (R_{sh}).

In Figure 1(l), it is noticeable that R_{sh} exhibits a slight decrease as the V_{Base} increases from 5 to 35 V. This change may be attributed to the involvement of hydrogen in the Ga_2O_3 channel region [2]. It is worth noting that the overall decrease in R_T for different *d* values is approximately two times R_c. The dominant behavior of R_c in response to changes in R_T confirms that the reason behind the improved ρ_c in dynamic measurement is primarily attributed to the β-Ga_2O_3/Ti-Au interface rather than changes within β-Ga_2O_3, specifically alterations in the effective potential barrier. Furthermore, an important observation is that the enhanced ρ_c after pulsed stress testing appears to be permanent, as shown in Figure 1.

Based on the thermionic-field emission (TFE) model and taking into account the ρ_c values depicted in Figure 1(k), it becomes evident that the improved ρ_c after the pulse test primarily results from a significant 0.051 eV decline in effective barrier height ($\phi_{b,eff}$) at the interface between metal and Ga_2O_3. The decrease of 0.051 eV represents a significant reduction in $\phi_{b,eff}$, and can contribute to a significant 65% reduction in dynamic ρ_c.

As shown in Figure 1(b), the dynamic voltage waveforms exhibit frequent transient transitions from low to high voltage within an extremely short period. These steep voltage rises can induce electrons within the previously passivated traps to transition into high-energy hot carriers [3]. After the activation of hot carriers, the previously passivated traps are reactivated and thus reengaged in facilitating the trap-assisted tunneling, which contributes to the decrease in $\phi_{b,eff}$ and thus the ρ_c reduction.

Conclusion. Through a series of pulsed measurements and bias voltage stress tests, we have demonstrated a significant 65% reduction in dynamic ρ_c with a V_{Base} of 35 V. This observed enhancement in ρ_c can be primarily attributed to a decrease in the $\phi_{b,eff}$ at the β-Ga_2O_3/Ti-Au interface during bias stress, thereby facilitating carrier tunneling near the ohmic contact. Our findings underscore the critical role of interfacial layers and trap effects in influencing the dynamic performance of ohmic contacts on β-Ga_2O_3.

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