Novel Epitaxial Nickel Aluminide-Silicide with Low Schottky-Barrier and Series Resistance for Enhanced Performance of Dopant-Segregated Source/Drain N-channel MuGFETs

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Abstract

We have developed a novel epitaxial nickel-aluminide silicide (NiSi2-xAlx) to reduce the Schottky-Barrier height (SBH) and series resistance in n-channel MuGFETs with dopant-segregated Schottky-Barrier source/drain (DS). 10% substitutional incorporation of Al in the Si matrix at the silicide-Si interface leads to a 37% reduction in the intrinsic SBH of nickel silicide. A further 42% effective reduction in the DSS SBH was attained with the combination of NiSi2-xAlx and Si-fins with an enhancement of 94% for NiSi2-Al, DSS MuGFETs over NiSi2-Al DSS MuGFETs was achieved, attributed to SBH lowering, series resistance reduction and possibly silicide strain effects. As a result, an excellent drive current of 882 µA/µm at VDS=VGS=1.2 V was achieved for NiSi2-Al, DSS MuGFETs with 55 nm gate length.

1. Introduction: Why SBH Engineering in DSS MuGFETs?

MuGFETs offer superior control of short-channel effects and scalability. A primary challenge, however, is in the formation of narrow Si-fins with low series resistance (SR) [1]. The silicidation of these narrow Si-fins in MuGFETs must be optimized to maintain a specific silicide-to-silicon contact area to minimize dopant segregation. Recently, dopant segregation at the Schottky-Barrier (DSS) MuGFETs demonstrated superior performance [3] over conventional MuGFETs, and addressed technological issues raised in Schottky-Barrier (DSS) MuGFETs demonstrated superior performance [3] over conventional MuGFETs, and addressed technological issues raised in conventional doped non-raised S/D NiSi MuGFETs compares well with a enhancement obtained in this work for DSS NiSi MuGFETs over conventional doped non-raised S/D NiSi MuGFETs [Fig. 1].

In part II, electrical device characteristics of DSS MuGFETs integrated with NiSi2-Al, are discussed and compared with DSS NiSi2-Al MuGFETs.

2. SBH Modification through Aluminum Metal Alloying?

20 nm thick metal films were deposited by sputtering using Ni and Ni-Al alloys for material characterization and subsequent device integration. As-deposited Al concentration of 10 & 20 % were investigated. Silicidation was completed with a one step rapid thermal anneal (RTA) process at 550 °C, 30 s in N2 ambient. Selective metal etch was divided into two parts. In part I, the materials characterization of the epitaxial nickel-aluminide-silicide (NiSi2-Al). In part II, electrical device characteristics of DSS MuGFETs integrated with NiSi2-Al, are discussed and compared with DSS NiSi2-Al MuGFETs.

3. Device Fabrication, Results and Discussion

To verify the feasibility of forming epitaxial low SBH NiSi2-Al/Si doped S/D schilde for improved MuGFET performance, we integrated our novel silicidation process into a standard MuGFET process flow [7] [Fig. 8]. The process features 20 nm wide and 45 nm tall fins with a 55 nm poly-Si gate and a 2 nm SiO2 gate oxide. For the DSS S/D junctions, As was implanted at a dose of 1x1016 cm-2 and annealed with a subsequent oxide.

Fig. 9 shows the TEM image (a) planar n-FET featuring NiSi2-Al, and (b) MuGFET with a fully-silicided Si-fin. The metallurgical gate length Lg is expected to be similar for both NiSi2-Al, DSS MuGFETs due to the comparable As segregation at the silicide-Si interface [Fig 7][b]].

The corresponding Al concentration after RTA was determined to be 18% for NiSi2-Al, DSS MuGFETs compared to NiSi-Al, DSS MuGFETs due to the ohmic contact area to minimize contact resistance [2]. Recently, dopant segregation reported by Kim [5]. Subsequent analysis in this work focuses on the materials characterization and integration of NiSi2-Al/S/D MuGFETs integrated with NiSi2-Al/S/D MuGFETs.

4. Conclusion

We have demonstrated a novel epitaxial nickel aluminide-silicide integrated with DSS technology and achieved a 42% reduction in electron-barrier height [i.e. φn = 0.133 eV] on n-Si(001). Successful integration of epitaxial NiSi2-Al/S/D into DSS MuGFETs delivers a 94% drive current enhancement. The combination of NiSi2-Al and NiSi2-Al DSS planar n-FETs indicating no adverse impact on the gate oxide quality with Al incorporation. Fig. 13 shows a series resistance reduction of 42 % for NiSi2-Al, DSS MuGFETs compared to NiSi2-Al, DSS MuGFETs. 94% hight enhanced in this work between doped S/D NiSi2-Al, DSS MuGFETs compared to NiSi2-Al, DSS MuGFETs, which contributes to the lower SR reduction and possibly silicide strain effects contribute to the drive current enhancement obtained. Our approach provides a CMOS compatible technique for further SBH engineering in DSS technology and eliminates the added complexity of a raised S/D approach to reduce the high parasitic SR/DSS MuGFETs with narrow Si-fins for future high-performance applications.

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References

Novel Silicides Engineering through Schottky-Barrier Height

Reverse Biased I(V) shows that NiSi\textsubscript{Al}, and NiSi devices have similar EOTs. Inset shows comparable gate leakage for both devices.

Extracted series resistance shows a 42% reduction in S/D series resistance for NiSi\textsubscript{Al}, DSS MuGFETs over the NiSi DSS MuGFETs.

\[ I_{DSAT} \text{ gain for NiSi}\textsubscript{Al}, DSS MuGFETs shows an enhancement of 198% over NiSi DSS MuGFETs. \]

Summary of \( I_{DSAT} \) gain for MuGFETs with NiSi doped S/D, NiSi DSS S/D and NiSi\textsubscript{Al}, DSS S/D.

*Fig. 1.* Schematic of a typical DSS n-FET. Modulation of the SBH is limited by As solid solubility in Si.

*Fig. 2.* I-V characteristics show NiSi SBH modification through Al alloying.

*Fig. 3.* SIMS profiles clearly show the higher Al concentration in the NiSi bulk and NiSi-Si interface for NiSiAl(20%) films.

*Fig. 4.* RBS spectra for NiSi\textsubscript{Al} films collected with the ion beam (a) 1 to the film in the (001) axis and (b) 4° off the (001) axis. Disappearance of dip in the Ni signal in (b) indicates epitaxial growth.

*Fig. 5.* (a) Cross-sectional TEM shows the formation of pyramidal shaped NiSi\textsubscript{Al} film. (b) High resolution TEM reveals an atomically flat NiSi\textsubscript{Al}/Si interface. Epitaxial formation is attributed to the small lattice mismatch of ~0.4 % between NiSi\textsubscript{Al} and Si(001).

*Fig. 6.* (a) \( \rho_{\text{Area}} \) transformation curve. SEM images obtained @ 700°C shows superior morphological stability for (c) NiSi\textsubscript{Al}, over (b) NiSi.

*Fig. 7.* SIMS profiles of DSS junctions. (a) As dose of 1x10\textsuperscript{17} cm\textsuperscript{-2} shows the highest concentration of segregated As. (b) Similar As concentration profiles were obtained for NiSi and NiSi\textsubscript{Al}.

*Fig. 8.* CMOS compatible process sequence employed in the fabrication of DSS n-MuGFETs.

*Fig. 9.* (a) TEM image of a NiSi\textsubscript{Al}, S/D planar N-FET with 55 nm poly-Si gate and PECVD slim spacers. (b) TEM image of a 25 nm fully-silicided NiSi\textsubscript{Al}, fin. Note: FIB cut was performed along the cut plane A-A' [inset of (b)], which overestimates the fin-width.

*Fig. 10.* (a) \( I_{DSAT} \) characteristics of NiSi and NiSi\textsubscript{Al}, DSS MuGFETs have similar OFF-current, DBIL and subthreshold swing. (b) \( I_{DSAT} \) shows 94% saturation drive current enhancement for NiSi\textsubscript{Al}, DSS MuGFETs over NiSi DSS MuGFETs at \( I_{DSAT} = V_{G} = V_{DS} = 1.2 \) V.

*Fig. 11.* Transconductance \( g_{m} \) for NiSi\textsubscript{Al}, DSS MuGFETs shows an enhancement of 198% over NiSi DSS MuGFETs.

*Fig. 12.* (a) C-V shows that NiSi\textsubscript{Al}, and NiSi devices have similar EOTs. Inset shows comparable gate leakage for both devices.

*Fig. 13.* Extraction of series resistance shows a 42% reduction in S/D series resistance for NiSi\textsubscript{Al}, DSS MuGFETs over the NiSi DSS MuGFETs.

*Fig. 14.* I-V shows ohmic behavior for NiSi DSS and NiSi\textsubscript{Al}, DSS junctions. This indicates a very low electron-barrier on n-Si(001).

*Fig. 15.* Reverse-biased I-V reveals that NiSi\textsubscript{Al}, DSS junctions have the highest hole-barrier in p-Si(001) for the systems investigated.

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