Extended Abstracts of the 22nd (1990 International) Conference on Solid State Devices and Materials, Sendai, 1990, pp. 79-82 **B-3-3**

Application of Hydrogenation to Improve GaAs/Si MESFETs and IC Performance by PECVD SiN

Mingxiang Li, Qingyi Tong
(Microelectronics Center, Southeast University, Nanjing 210018, P.R.China)
Gang Zou, J.Deboeck, M.Von Rossum, G.J. Declerck
(IMEC, Kapeldreef 75, B-3030 Leuven, Belgium)

GaAs / Si hydrogenation effect utilizing PECVD SiN overcoating and post annealing are reported. Atomic hydrogen can penetrate into GaAs on Si substrate and passivate deep level defects and silicon shallow donor, but most silicon donor can be recovered by post annealing at rather low temperature while deep levels remain passivated. This processing creates no additional deep levers in GaAs / Si and can provide significient improvements on GaAs / Si MESFETs and circuits performances. Meanwhile, this processing has great compatibility with conventional GaAs IC processing and easy to be implemented.

Introduction:

Although great progress has been achieved in GaAs / Si technology, very high densities of threading dislocation, dangling bond and defective level is still one of the main problems which restrains its further application. These defects can act as generation – recombination center and reduce radiative efficiency of optical device. They can also increase defect current and induce premature breakdown in electrical device.

Hydrogenation is an effective way to reduce the density of these defects. Atomic hydrogen (H) can passivate dangling bond, defective level and shallow donor level in GaAs, but, whereas the latter can be recovered by post annealing, the formal remains fully deactivated within certain temperature region.

Hydrogenation can occur in low R.F. H plasma and H–contained reactive ion etching ambient. S.J. Pearton et al.[1] employed H plasma treatment on GaAs / Si to passivate defects and increased the reverse breakdown voltage of a Schottky diode from 2.5 to 6.5V. However, a reduced barrier height is exhibited by H bombardment. N. Chand[2] revealed that Au Schottky contact to GaAs / Si after hydrogenation shew higher reverse bias current than that without H plasma treatment. Because H plasma introduced more defects in GaAs / Si and it was supported by DLTS measurement.

Here, we report our experimental results of hydrogenating GaAs / Si sapmles by overcoating and post annealing PECVD SiN, utilizing NH3, SiH4 and N2 as sourses, which contains H with concentration higher than $10^{22}cm^{-3}$. Compared with exposing sample to 30kHz H plasma, this method creates no additional deep levels, avoids As deficiency formation. Meanwhile, it has greater compatbility with conventional GaAs IC processing and easier to be performed. Significient improvements have been obtained from GaAs / Si MESFETs and IC undergoing such hydrogenation, and one SiN / polyimide double–layer interlayer techniqe has been developed for GaAs / Si IC processing, which can implement hydrogenation and IC passivation at the same time.

Experiments and Discussions:

The GaAs layers were grown by MBE on (100) 4° off toward [011] Si substrate. In GaAs / GaAs strain layer supperlattice was introduced to filter threading dislocation and followed by 2.0μm thick S.I. growth. The active layer thickness is 0.15μm and doped by silicon at 2e17cm−3. The total thickness of epitaxial layer is about 3.5μm. MESFETs active regions were seperated by mesa etching, the ohmic and Schottky metalization structures were 5nmNi / 100nmAuGe / 15nmNi / 80nmAu and 40nmTi / 15nmTiW / 150nmAu, respectively. After clean, the wafers were sent into PECVD parallel plate reactor to deposite 100nm SiN. The conditions were: 20w applied power, 350mToor vacuum, 300℃ table temperature. The deposition rate was 7~ 8nm / min. During deposition, H could gain enough energy to penetrate into GaAs and passivate dangling bond, defective level and shallow donor. This reaction caused rather great shift of threshold voltage of GaAs / Si MESFETs as shown in Table 1, the values of △Vth1. It was found that △Vth of GaAs / Si MESFETs were much greater than that of GaAs / GaAs MESFETs. The typical values were 0.5v and 0.1v, respectively.

Rapid thermal annealing was employed to investigate the recovery of passivated Si donor (by means of △Vth) versus post annealing temperature, T. The annealing duration was fixd at t=5 min., and the results are shown in Fig.1.

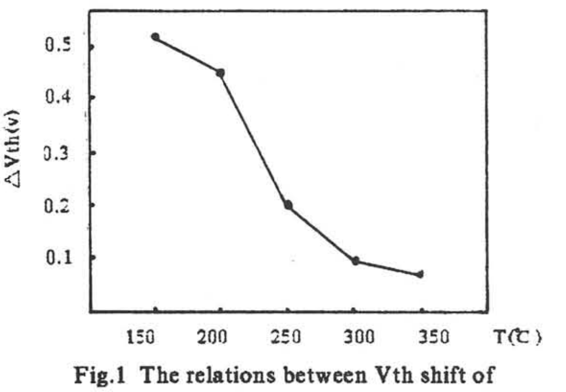

Fig.1 The relations between Vth shift of GaAs / Si MESFET and post annealing T

It was noticed that △Vth begin to decrease considerablly when annealing T=200℃. When T reachd 300℃, △Vth decreased to 0.1v.

We also performed in-situ annealing of GaAs / Si samples inside PECVD chamber. The procedure worked as: first to deposite few tens of nm SiN, then interrupt the deposition and implement annealing at table temperature, 300℃, for 5 min. and then continue the deposition until required thichness of SiN was reached. By this treatment, △Vth of GaAs / Si MESFET could be lower than 0.2v, or even lower than 0.1v in some case.

The fact that hydrogenated Si donor can be nearly fully recovered at rather low temperature (T < 350℃) makes great convenience for implementing as-discribed hydrogenation even after device has been fabricarted. The rather low annealing temperature will not influence device stability and reliability. As SiN itself can work as protective layer of GaAs surface, less deficiency formation can be expected.

DLTS spectra before and after hydrogenation are shown in Fig.2. After hydrogenation and post annealing (350℃, 5min), M1, M4 traps are nearly completely passivated and M3, M6 trap concentration are decreased. In addition, no deep level is created by SiN overcoating.

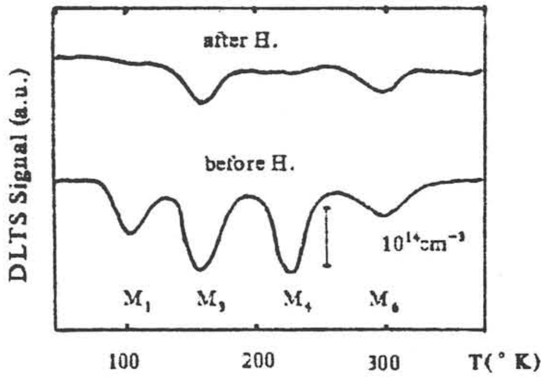

Fig.2 DLTS spectra of GaAs / Si before and after H.(hydrogenation). T=300℃ t=5min.

The temperature dependence of reverse bias I–V characteristics of GaAs / Si Schottky contact were checked before and hydrogenation. After SiN overcoating and post annealing (350℃, 5min), the reverse bias current becomes more temperature dependent. So, hydrogenation is helpful to reduce the density of defect which enhance the tunneling probability of carriers and its conduction is not temperature activated.

Device and IC Applications

The described hydrogenation was applied to device and IC fabrication. We implemented it before and after mesa seperation, together with ohmic contact SiN cap alloy, and did it with device passivation after MESFET had been fabricated. Very similar results have been obtained. One SiN / Polyimide double–layer interlayer technique, which can implement hydrogenation and device passivation at the same time, has been developed, too.

Significient improvements have been achieved after hydrogenation as can be seen from $\triangle$ n3 and $\triangle$ ϕbi3 in Table 1. Obviuosely, gate doides perform better after hydrogenation, with 0.1 average decrease of ideality factor and 50mv average increase of barrier height which equals to one order of magnitude reduction of reverse bias current. The fact that Vth shifts positively while transconductance remains nearly unchanged is probably related to the increase of channel electron mobility after hydrogenation.

Noise figure has been measured befored and after hydrogenation. At 2 GHz, for 2 stage amplifier, the noise figure decreases from 5.1db before gydrogenation to 3.6db after hydrogenation.

In Fig.3, a premature breakdown of GaAs / Si gate diode is restored by hydrogenation. The output conductance and subthreshold conduction have been reduced after hydrogenation as shown in Fig.4 and Fig.5, respectively. In Fig.6, we show a improved transfer characteristics of a BFL invertor, both logic swing and voltage gain have been enlarged after hydrogenation. Similar results have been obtained from NAND and NOR gates.

Conclusions:

Hydrogenation, utilizing PECVD SiN overcoating and post annealing, is an effective way to improve GaAs / Si MESFETs and IC performances. During SiN deposition, H atoms can gain enough energy to penetrate inside GaAs and passivate dangling bond, defective level and shallow Si donor. Most of the passivated Si can be recovered by post annealing at rather low temperature while deep traps remain to be passivated. The improvements of GaAs / Si MESFETs and IC performances and the reduction of excess conduction, noise figure are due to defective levels, dangling bond and electric active dislocation passivation by as–discribed hydrogenation.

References:

1. S.J.Pearton, C.S.Wu, Michael Stavola, F.Ren, J.Lopata, and W.C.Dantremond— smith; Appl. Phys. Lett, 51(7), 17 August, 1987, 496
2. N.Chang, R.Fischer, A.M.Sergent, D.V.Lang and A.Y.Cho; Material Research Society Symposia Proceedings Vol.91 "Heteroepitaxy on silicon II", 1987, 233

Table 1: GaAs / Si MESFETs parameters changes before and after hydrogenation

	T1	T2	T3	T4	T5	T6	T7	T8
△Vth1 (mv)	501	502	497	512	521	489	501	453
△Vth2 (mv)	103	108	96	94	103	105	96	102
△Vth3 (mv)	112	104	103	112	79	120	98	98
△n3	−0.12	−0.09	−0.11	−0.09	−0.08	−0.11	−0.09	−0.13
△φbi3 (mv)	49	51	48	48	49	52	47	48
Gm3 (ms/ mm)	129	136	138	124	139	123	135	133

where the foot-note implies different procedures as:

1: direct SiN deposition as normal, without post annealing

2: after SiN overcoating and in-situ annealing at 300℃ for 3min

3: aftef 100nm SiN overcoating, the wafer underwent post-annealling at 350℃ for 3min

MESFETs $T_1 \sim T_8$ have the same dimensions, Lg = 1.5μm, Wg = 50μm and their designed Vth = −1.5v

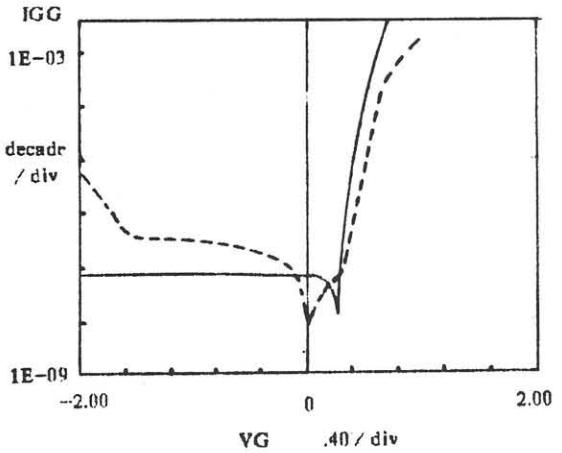

Fig.3 Schottky diode characteristics before (dashed line) and after (solid line) H.(250℃, 10min)

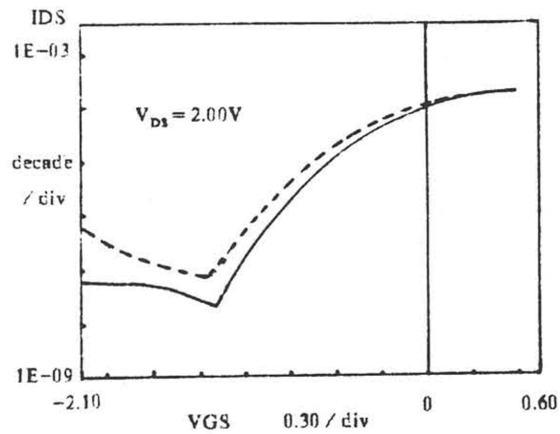

Fig.5 MESFET subthreshold conduction before (dashed) and after (solid) H.(350℃, 3min)

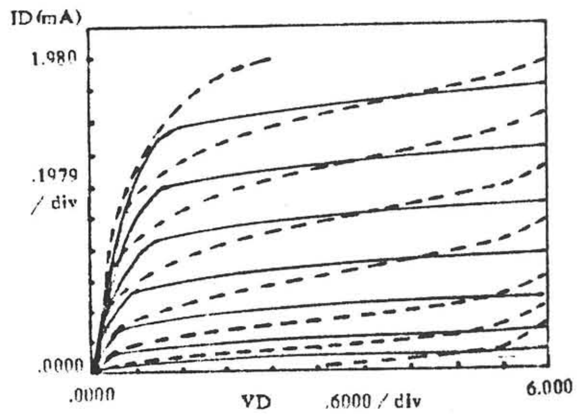

Fig.4 MESFET output characteristics before (dashed line) and after (solid line) H.(350℃, 3min)

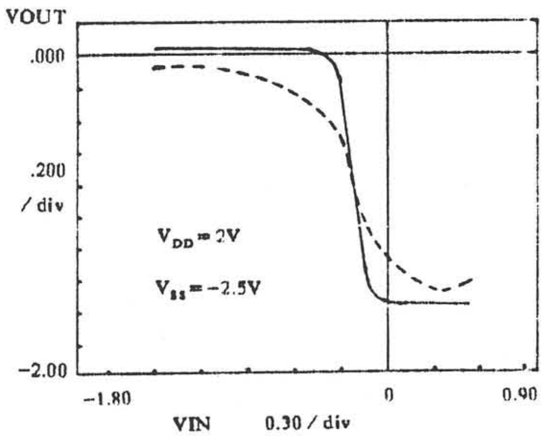

Fig.6 invertor transfer characteristics before (dashed) and after (solid) H.(350℃, 3min)