Extended Abstracts of the 2007 International Conference on Solid State Devices and Materials, Tsukuba, 2007, pp. 344-345

P-1-11

# Tuning of Work Function of Er-germanide Metal Gates on High-K Dielectric

S. L. Liew, D. H. L. Seng and D. Z. Chi

Institute of Materials Research and Engineering
3 Research Link, 117602 Singapore
Phone: (65) 6874 8354 E-mail: sl-liew@imre.a-star.edu.sg

## 1. Introduction

Metal germanides have been demonstrated for their applications to MOSFETs as gate electrodes. In particular, NiGe has low electrical resistivity, good thermal stability and work function close to $E_v$ of Si for p-MOS gate [1]. On the other hand, Er-germanides as a candidate for gate electrode has not been widely reported. A recent study showed that $ErGe_x$ on $SiO_2$ has a work function of 4.05 eV [2] which corresponds to the $E_c$ of Si. In view of the need for high k dielectric to replace $SiO_2$, the suitability of $ErGe_x$ on the former needs to be investigated. It was also attempted in this study to modulate the work function of $ErGe_x$ through Ti alloying with Er. We found that the work function of $ErGe_x$ can be tuned from ~4.24 eV to ~4.85 eV in response to the atomic ratio of Ti.

## 2. Experimental Procedure

Er and Ge were deposited sequentially onto HfAlON on p-Si(100) substrates through a shallow mask to form capacitors. The HfAlON was grown via MOCVD. For samples with Ti as well, the atomic ratios of Er and Ti were varied through power and time during co-sputtering of the metals. For all samples, sufficient thickness of TiN was deposited to serve as a capping layer for Er. The samples were annealed in RTP chamber at 400 $^oC$ for 60s in $N_2$ ambience. Electrical (C-V and I-V) and material characteristics of the capacitors were characterized.

## 3. Results & Discussion

Fig. 1 shows the C-V curves of the different capacitors. With 16 nm thick Ge, the C-V curve is not normal suggesting a leakage in the dielectric layer. Capacitors with a thicker Ge layer demonstrate typical accumulation and discharging behaviours. The experimental data could be fitted well with simulation using EOT and $V_{fb}$ as fitting parameters. The curves shift to the right with increase in the Ti content, indicating that Ti increased the $V_{fb}$ of the capacitors. In addition, Ti did not result in significant change of the EOT as indicated by the similar capacitance values. The $V_{fb}$ and EOT values obtained from simulation were then plotted as shown in Fig. 2. The y-intercept increases with Ti addition indicating higher work function (WF). Fig. 3 shows how the WF obtained from extrapolation of the $V_{fb}$-EOT curves varies with atomic ratio of Ti. Without Ti, the WF is outside the $E_c$ level of Si. Ti increases the WF of the capacitors. With 35% Ti, WF is ~4.24 eV which is close to the $E_c$. With 50% Ti, WF is ~4.87 eV which is similar to values reported for p-MOS gate candidates. Ti has a higher work function than Er (between $E_c$ and mid-gap of Si). Adding Ti to Er will increase the work function of Er-germanides. The I-V characteristics of the diodes were also determined. The leakage currents for the capacitors were generally low, as low as ~$10^{-8}$ A/cm$^2$ (at –1 V) for EOT ~3 nm of dielectric (Fig. 4).

The elemental depth profiles of the capacitors were analysed with SIMS in Fig. 5. The plots clearly show a layer of Er-germanide was formed upon annealing. It is also evident that Ti co-existed with Er in the germanide layer. The Er profile is not significantly different from that of the as-deposit sample, suggesting there is no diffusion of Er towards the HfAlON even upon annealing. Excess metal diffusion towards the dielectric might degrade the integrity of the capacitors [3]. The XRD scan in Fig. 6 shows that $ErGe_x$ was formed with x between 1.33 and 1.8 [4]. Ti-germanides phases were not expected to form in this study as they usually require higher temperatures [5]. The phase diagram of Ti-Er is characteristics of that of a solid solution with no intermetallic compounds [6]. Ti co-existed with Er to form $Er(Ti)Ge_x$.

## 4. Conclusions

The work function of $ErGe_x$ on HfAlON can be tuned from 4.24 to 4.85 eV through Ti alloying with Er. The capacitors have low leakage currents. Material investigations showed that Ti co-existed with Er to form $Er(Ti)Ge_x$ phase.

## Acknowledgements

S. L. Liew would like to thank Rinus T. P. Lee (NUS, Singapore) for provision of samples and R. Li (NUS) for assistance in the C-V measurements.

## References

[1] C. H. Huang, D. S. Yu, A. Chin, C. H. Wu, W. J. Chen, C. Zhu, M. F. Li, B. J. Cho, D. -L. Kwong, IEDM Tech. Dig. (2003) 319.

[2] Y. Tsuchiya, M. Koyama, J. Koga and A. Nishiyama, *Extended Abstracts of the 2005 International Conference on Solid State Devices and Materials* (2005) 844.

[3] J. D. Chen, H. Y. Yu, M. F. Li, D. -L. Kwong, M. J. H. Dal, J. A. Kittl, A. Lauwers, P. Absil, M. Jurczak and S. Biesemans, Elec. Dev. Lett. 27 (2006) 160.

[4] Erbium Oxide Powder Diffraction File No. 8-50, Erbium Germanium Joint Committee on Powder Diffraction Standards (JCPDS) Nos. 85-2338, 18-0484, 88-0903.

[5] S. P. Ashburn, M. C. Ozturk, J. J. Wortman, G. Harris, J.

Honeycutt and D. M. Maher, J. Electron. Mater. **21**, 81 (1992).
[6] T. B. Massalski, J. L. Murray, L. H. Bennett and H. Baker (ed.), *Binary Alloy Phase Diagrams*, American Society for Metals (1990).

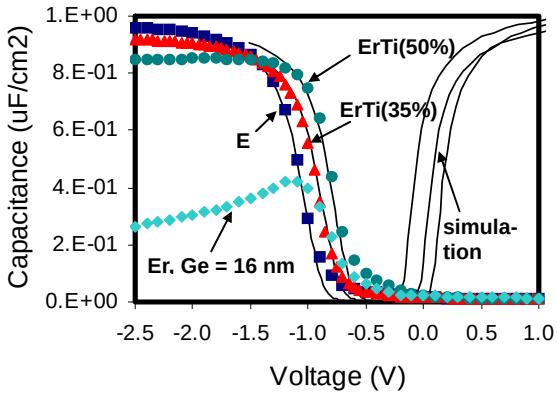


Fig. 1 C-V plots of Er-germanide capacitors on HfAlON

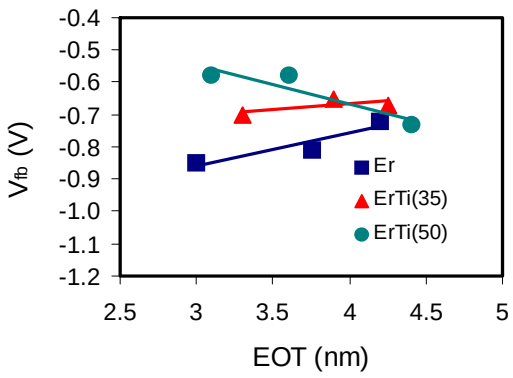


Fig. 2 Plots of $V_{fb}$ vs. EOT of Er-germanide capacitors.

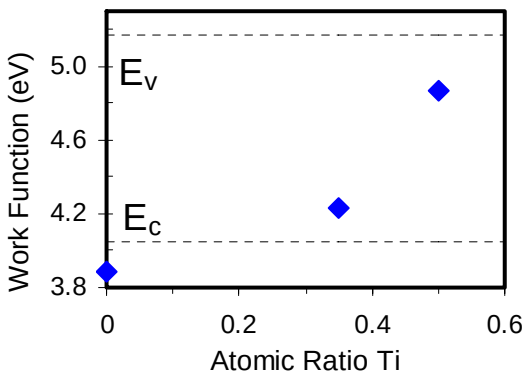


Fig. 3 Dependence of work function of Er-germanide gate on atomic ratio Ti.

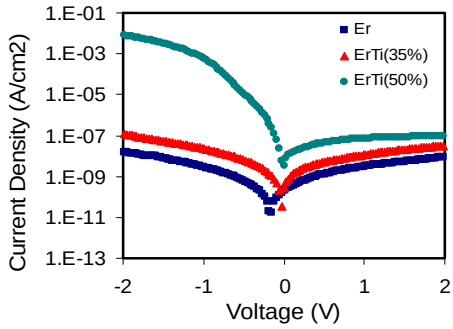


Fig. 4 Leakage current of Er-germanide capacitors.

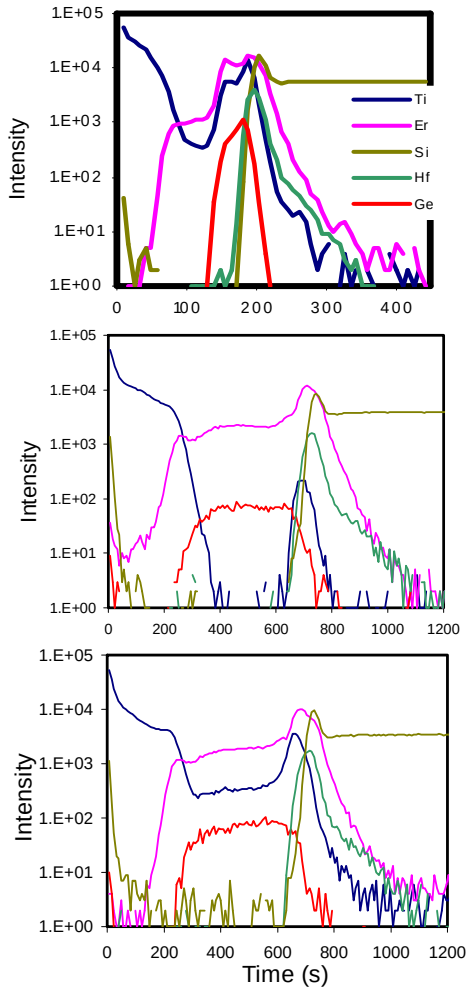


Fig. 5 SIMS plots of Er-germanide capacitors. (Top) As-deposit (Middle) Er (annealed) (Bottom) ErTi(35%) (annealed).

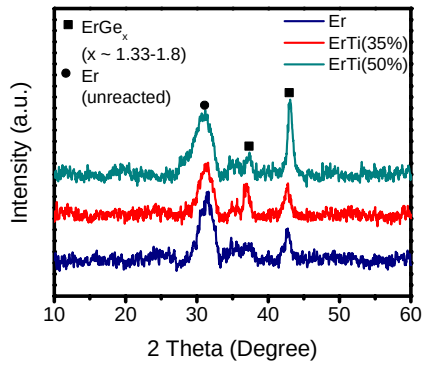


Fig. 6 XRD scans of Er-germanide capacitors.