Thermal atomic layer deposition of boron containing oxide films as solid sources for doping of advanced memory devices

Yongqing Shen[1, #], Shuai Yang[2, #], Jinjuan Xiang[1*], Jinbiao Liu[2], Jianfeng Gao[2*], Guilei Wang[1*], Chao Zhao[1]

[1]Beijing Superstring Academy of Memory Technology, Beijing, China

[2]Institute of Microelectronics, Chinese Academy of Sciences, Beijing, China

#These authors contribute equally to this work.

*Email: Jinjuan.Xiang@bjsamt.org.cn; gaojianfeng@ime.ac.cn; Guilei.Wang@bjsamt.org.cn.

In recent decades, with the continuous scaling down of device dimensions and the emergence of complex three-dimensional structures, conventional ion implantation cannot meet the requirements of non-damage and uniform doping of the nonplanar transistor architecture. Atomic layer deposition (ALD) is one of the most promising methods for forming controlled and conformal dopant-containing layer. Compared to plasma enhanced ALD, thermal ALD has better ability for achieving the required conformity conditions and high scalability for 3D structures with higher AR ratio. By combing of ALD with the heat-driven annealing, non-damage and conformal doping in Si can be achieved. However, ALD doping still faces many challenges, one of the big issues is that B_2O_3 films cannot grow sustainably, which hinders its further application [1, 2].

In this paper, Al_2O_3 and SiO_2 layer were used as enhance layer to promote the deposition of B_2O_3 by thermal ALD. By using Al_2O_3 interlayer, low lewis acidity of Al−OH- was formed. Boron is evenly distributed in $B_xAl_{1-x}O_y$ film with a content of about 15 at. %, which is higher than that in $B_xSi_{1-x}O_y$ film. After rapid thermal annealing, the maximum doping concentration of B can reach 2E20 atom /cm^3, and the doping concentration of Al in Si is low. When SiO_2 as the enhance layer, the maximum B doping concentration is 3E19 atoms /cm^3. In addition, the content of B in $B_xSi_{1-x}O_y$ film and doping concentration in Si are higher at low B:Si ratio of 4:3 than at B:Si of 5:1, which is mainly due to the fact that enough SiO_2 layer can promote the growth of B_2O_3 more effectively. Uniform and dose-controlled doping achieved by this thermal ALD doping is believed to have great application prospects in 3D structures device, especially for vertical stacked dynamic random-access memory (DRAM).

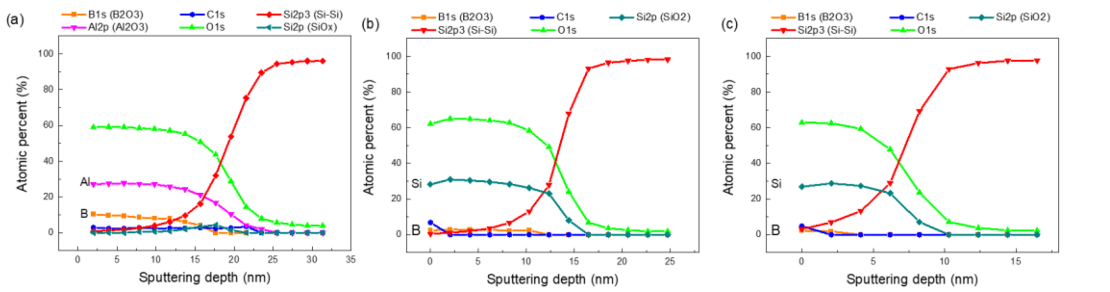

Fig.1 XPS depth profile data of (a) ALD $B_xAl_{1-x}O_y$(B:Al =15:1), (b) ALD $B_xSi_{1-x}O_y$ (B:Si =4:3) and (c) ALD $B_xSi_{1-x}O_y$ (B:Si =5:1) films by O_3.

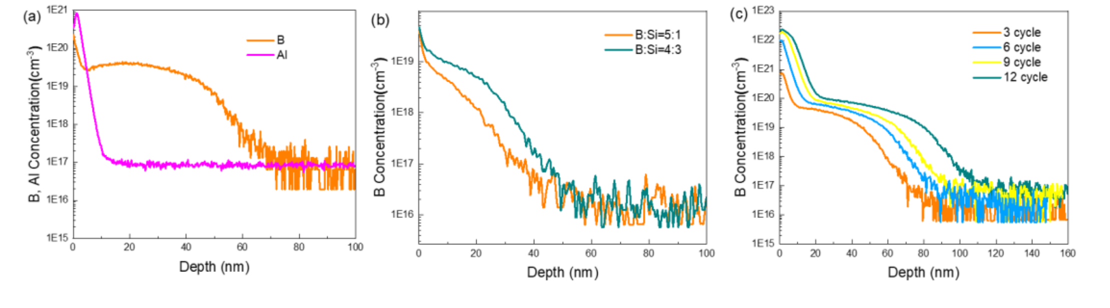

Fig. 2 SIMS depth profiles of (a) $B_xAl_{1-x}O_y$ (B:Al =15:1), (b) $B_xSi_{1-x}O_y$ films (B:Si =4:3) and (c) $B_xAl_{1-x}O_y$ with different cycle after anneal.

[1] F. Mattelaer, M. Van Daele, M.M. Minjauw, M. Nisula, S.D. Elliott, T. Sajavaara, J. Dendooven, C. Detavernier, Chem. Mater. 32 (2020)

[2] A. U. Mane, J. W. Elam, J. Vac. Sci. Technol. A, 34 (2016)