# Chapter 5

# Conclusions

This dissertation has widely presented the study of the growth of Os and the properties of magnetic films with an Os layer. Several important results are summarized.

The thermal issue was first to pointed out in the study of short time and high temperature thermal treatment of PtMn-based MTJ system. Even though the MTJs could bare the short time and high temperature annealing for PtMn phase transformation; however, the post-annealing influenced on the overall performance of a MTJ. That is really a key reason why the thermal stability must be paid attention to. Although Os did not replace the Ru layer in SAF structure to enhance the magnetic properties; however, our AES depth profile results indicated the Os was more stable than Ru after 400°C annealing. After 400°C annealing, no clear diffusion evidence was found in CoFe/Os/OsMn system, and its hysteresis loop showed a slightly increased $H_C$ and $S > 0.9$ even though the Os was as thin as 0.3 nm. Such results meant the Os layer could stop the Mn diffusion, thus, it has potential to be a new type of diffusion barrier of Mn atoms in magnetic film.

On the other hand, since the hcp structure of Os showed that its basal (0002) plane has the same atomic arrangement of a (111) plane in fcc. Thus, Os on amorphous $SiO_2$ acting as buffer layer could effectively enhance fcc (111) growth of IrMn and CoFe when the thickness of Os was larger than 5 nm, while the $H_{ex}$ of the CoFe/IrMn was also proportional to the Os thickness. Compared with the weak growth of CoFe (111)/ IrMn (111) grown on Os/$SiO_2$, the fcc (111) of CoFe/IrMn grew more epitaxially on hydrogen terminated Si substrates due to lower surface lattice mismatch. With an Os buffer layer, CoFe/IrMn grew with more texture structure on H-Si (100) than on H-Si (111). Furthermore, the Os buffer could tune the IrMn crystalline structure, and IrMn (000) was restrained and made the surface change into a suitable surface mesh to grow the IrMn (111) on H-Si (100) as $t_{Os}$ increased from zero to 30 nm. The better fcc (111) structure of CoFe/IrMn grown on Os/Cu/H-Si (100) resulted in a more coherent magnetization reversal process; thus, a hysteresis loop with large S (~ 1) was obtained. On the other hand, these textured CoFe/IrMn film showed better thermal stability than the non-textured one, and the 50°C and 75°C of improvement on the temperature at which the $H_{ex,max}$ appeared and the $H_{ex}$ disappeared could be observed. The insertion Os layer between CoFe/IrMn reduced the $H_{ex}$; however, the textured CoFe/Os/IrMn showed higher temperature to reach the largest $H_{ex}$ and higher temperature to lose the $H_{ex}$ than the sample without the insertion Os barrier layer. Furthermore, these annealed textured CoFe/Os/IrMn showed larger $H_{ex}$ than that of the as-deposited state even the insertion Os was only 0.1 nm. As mentioned above, using Os as a buffer layer and a diffusion barrier could result better crystalline structure of CoFe/IrMn with better thermal stability.

We have also study the growth of Os (0002) on hydrogen terminated Si substrates. With a Cu seed layer grown on H-Si (100), the Os film was grown along its [0002] direction normal to the substrate plane by the MMES method. Such a weakly grown 6-fold Os film showed a 12-fold in-plane symmetry resulting from was two sets of (0002) epitaxial grain. Furthermore, in order to form a suitable surface mesh on the H-Si (111), buffer layers of Au, Cu/Au, Cu/Ag, and Ag were confirmed to form better fcc (111) surface mesh, and thus, the epitaxial Os (0002) film was obtained. Among these candidates, Ag seed layer brought the best Os (0002) film than the other seed layers due to the lower surface energy and the lowest lattice mismatch. The strong Os (0002) diffraction peak and the 6-fold symmetry of {10$\underline{1}$1} in φ scan data indicated the epitaxy growth of Os (0002) was actually well-controlled.

As mentioned in this dissertation, Os shows good potential to be a buffer layer and a diffusion barrier, and the growth of Os (0002) can be well-controlled on Cu surface. Thus, these superior properties permitted Os would play an important role, as a multi-functions material (as shown in the Fig. 5-1), on combining ULSI processes with MTJ manufacturing for high density MRAM products. it is permitted that Os has potentials to be applied in integrating the ULSI and MTJ processes.

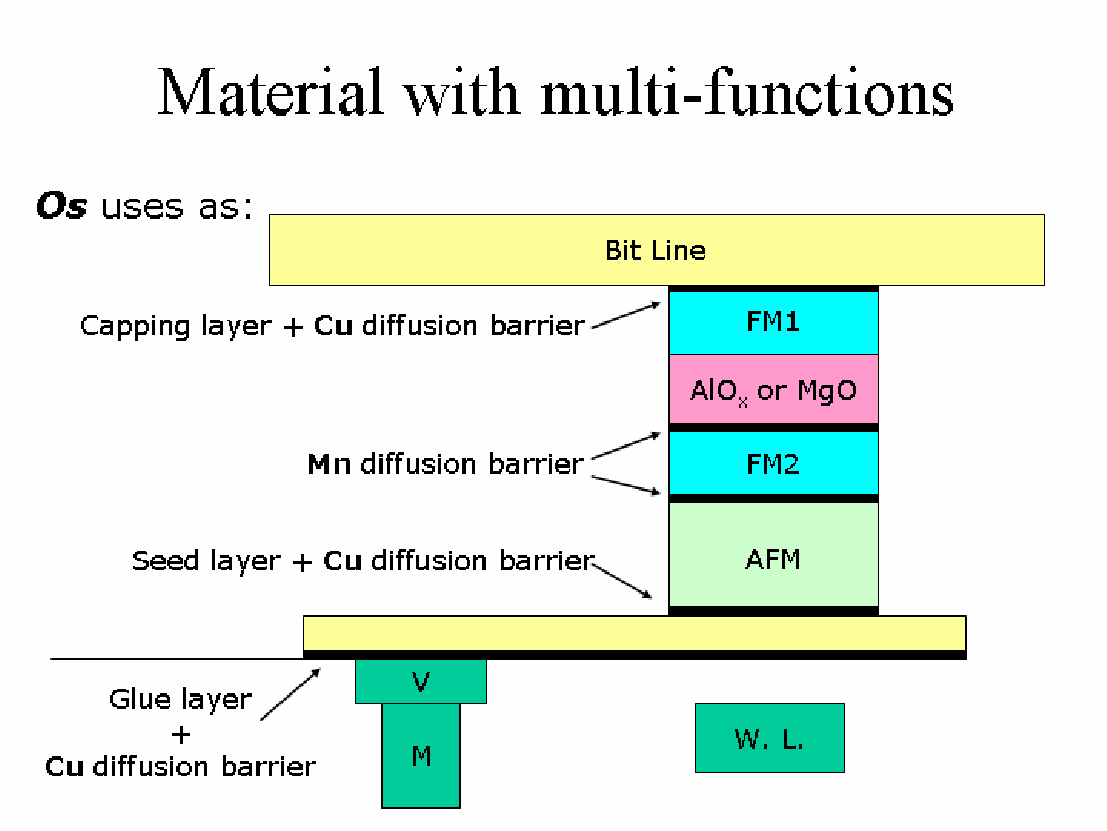


Fig. 5-1 Schematic illustration of the Os uses on combining ULSI processes with MTJ manufacturing.