Chapter 4
Mass-Production Memories (DRAM and Flash)

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4.1 Introduction

Computers process information and store data. Their workloads can be duly classified into computing-centric and data-centric. In the computing-centric workload, the supreme performance of a microprocessor, which is composed of logic gates, is of primary importance. Issues related with logic gate formation will be discussed in chapters 7 and 8. On the other hand, memory plays a more important role in data-centric workload [1]. As the world is more closely connected by internet and the amount of end-user generated data is increasing exponentially (such as video images uploaded onto YouTube), the usual computer workload shifts more to the data-centric variety. The amount of indexed online data was estimated to increase from ~5 exabytes in 2002 to ~280 exabytes in 2009, a ~56-fold increase in only 7 years [2]. However, the computing power increase estimated by the increase in the number of logic gates and its operation speed according to Moore's law is only ~16-fold for the same period, suggesting the current trend of exploding data. Most computer users nowadays "search and see" rather than "process" information. This trend means that the importance of memory in any form of computers is ever-increasing. As of the end of 2011, the shipping of flash memory, which is purely a memory-related device, exceeds that of dynamic random access memory (DRAM), which is more closely related with microprocessor operation. This trend clearly shows a very large change in the worldwide computing environment; memory becomes more and more important.

This chapter describes the memory devices and ALD-related fabrication processes. As described in the Introduction chapter, memory devices can be classified into 2 groups: the mass-production memories, including DRAM, Flash, and static RAM (SRAM); and emerging memories, such as phase-change RAM (PcRAM), magnetoresistive RAM (MRAM), and resistive RAM (ReRAM), or niche markets such as ferroelectric RAM (FeRAM). At the moment, MRAM and ReRAM are of little relevance for ALD or are too premature to be considered from the ALD point of view, so they are not discussed in this chapter. From the fabrication point of view, SRAM is identical to the logic gates, so it is also not discussed here.

4.1.1 Role of DRAM and Flash Memories in a Computer

Dynamic random access memory (DRAM) works as the main memory in every modern computer, from high-end server computers to simple hand-held devices. Computing in any computer requires two key information sets; programs, and the data to program with. Both sets are stored as a form of 'bits' in the core memory part of a computer. Any computed output that comes from these actions is also stored as a data set within different parts of the memories that comprise the computer. Up to now, the conventional hard disk has been the primary memory element for all data storage (program and user data). However, the mechanical motions of the magnetic hard disk limit the data access time for both read and write operations, making them incompatible with the modern high speed microprocessors. Microprocessors actually require a considerably large amount of memory for device operation. The primary temporal memory element to cope with this issue is an embedded SRAM, which is fabricated concurrently with the logic circuits. However, due to its large cell size, the memory density of SRAM is limited to a rather low level, and a massive amount of data must inevitably be stored away in the DRAM portion during computer operation. In addition, the program that controls microprocessor operation must also be retrieved from the hard disk and loaded into the DRAM. Therefore, DRAM must have a memory density large enough to satisfy these requisites, which is typically at least a few gigabytes for modern computers to fluently operate. In everyday life, we sometimes see the computer freezing its functions momentarily as the hard disk operates when a computer with an insufficient main memory is used. This is usually due to the dumping of an abnormally large data set that cannot be handled by the limited DRAM when information is transferred in and out of the hard disk. It is not difficult for us to infer from these everyday experiences that the main memory itself plays a role as important as high speed processors for modern computers in terms of performance. It is, therefore, evident that main memories should have high density, high speed, robust data storage, and an almost unlimited number of writing/reading cycles, which can all be achieved only from DRAM at present. If DRAM technology persist its evolving

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