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Late 2000s

Adoption of high-k materials and metal gates for high-speed transistors

~ Process Technology ~

Along with the miniaturization of the transistor, the gate oxide film thickness was also decreased according to Moore's law, but gate leakage due to tunneling current became significant from around 15 nm. In order to overcome this problem, development has advanced in the direction to make effective electrical thickness thinner by increasing the dielectric constant, while maintaining the physical film thickness. Following the initial application of an oxynitride film, a high-k material having a higher dielectric constant has been introduced. In the silicon gate, a depletion layer is formed in the gate polysilicon, which also hinders the thinning of the gate insulating film, so the use of metal for the gate electrode has progressed.

The high-k metal gate methods are largely divided into two; gate-first and gate-last. The former is a process of forming a laminated film of a high-k film and a metal, which is then etched by RIE. This is basically in line with the traditional process, and it is widely adopted in Japan. The high-k gate insulating film in this structure was first used in 55nm CMOS by NEC. The latter is a method to use damascene method, and it was first adopted for 45nm processors by Intel. Hafnium-oxide based materials are widely used for high-k materials, and tantalum nitride and titanium nitride are widely used for metal gates. They are formed by single-wafer MOCVD, ALD (Atomic Layer Deposition), or PVD. In addition, various organic source gases for forming high-k and metal films have been newly developed and introduced.

The initial tasks were to search for suitable materials for the insulating films, metal films, and film formation method. Also, the introduction of the metal gate has various influences on the threshold value of the transistor, and the process of making the CMOS is complicated, and they still remain as the issues to be solved. The former is solved by selection of additive metals and optimization of thermal process.

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