Progressive Furnace Process Technology for Advanced Gate Stack

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Progressive furnace technology approaches for the up-to-date and next generation gate stack processes are reviewed on several key processes such as ultra-thin gate dielectrics. It will be shown that hot wall furnace technology still continues to provide practical and sound solutions which are highly competitive with single wafer equipment approach and have some unique advantages such as excellent process performance (both film quality and uniformity control), flexibility, stability, and low cost of ownership. The paper will review the recent progress in the advanced furnace process application on (1) ultra-thin gate oxide/oxynitride for logic devices, (2) Tunnel Oxide for flash memories, (3) poly-SiGe gate electrode, (4) high-k dielectrics, etc.

Recent aggressive scaling of gate dielectrics has created many difficult challenges on thermal processing equipment technologies. It seemed as if to accelerate the transition from conventional batch furnace technology to single wafer tools. However, extensive and continual efforts to improve hardware architecture made it possible that furnace technology evolution meet the process requirements for FEOL thermal processing in scaled devices. Hot-wall furnace system has many advantages because it is iso-thermal processing and has a good cylindrical symmetry to assure excellent uniformity control, and pure quartz-ware chamber with new metal free heater elements is capable of ultra clean process together with in-situ dry cleaning steps. Innovative furnace architecture enabled fast-ramp features(100-200C/min) which extended the range of applicable thermal processing much toward single wafer equipments(RTP) and now providing solutions covering the gap between batch system and single wafer systems.

Most critical process is ultra-thin gate dielectrics formation. The issues are (i)extraneous oxide growth(surface state control) during ramp-up stage ,(ii)uniformity control,(both in ramp-up sequence and oxidation steps), and (iii)film quality control. There was a criticism that furnace process could not form ultra-thin oxide/oxynitride with good uniformity control, because of narrow wafer-to-wafer pitch size and additionally, temperature gradient during ramp-up(wafer temperature tends to be higher at the edge than the center during ramp-up). But it was found that low pressure operation greatly improves both in-wafer and wafer-to-wafer uniformity allowing the use of even conventional large batch size processes. Total gas flow strongly affects in-wafer uniformity of thermal oxide by gas cooling effect selectively on the wafer edge during ramp-up, and its optimization enables excellent uniformity control of ultra-thin oxide down to 1.0-1.3nm range. Film quality control is a big concern for ultra-thin oxide process. High temperature (800~850C), reduced pressure wet oxidation using catalytic water vapor generator(C-WVG) shows distinct superiority of film qualities over dry oxidation process. Low pressure C-WVG wet oxide process shows ~50% lower leakage current over a wide thickness range down to less than 1.5nm, together with superior TDDB characteristics. The film quality was found to be sensitive to pre-oxidation steps such as surface pretreatment and ramp-up conditions (oxygen partial pressures etc.). Optimization of oxygen partial pressure assures sound film properties (Tdb etc.) avoiding surface degradation due to oxygen deficiency.

Use of oxygen radical species for gate oxidation leads to film quality improvement specially on film reliabilities. There are multiple ways to utilize radical oxidation for thermal processing and one example is ozone gas processes using external ozonizer apparatus. Low pressure operation less than 1torr prolongs the life time of oxygen radicals and enables sound process control over entire batch size. An interesting application is the use of low temperature ozone oxidation as a pre-oxidation treatment before ramp-up for high temperature gate oxidation. It was found that 300C low temperature ozone treatment is very effective to remove organic contaminant on the wafer surface and also can form high quality thin oxide which plays a role of a good protective layer against surface degradation during ramp-up sequence. Evaluation results of thin wet oxidation(850C) with low temperature ozone pre-treatment(300C) showed improvement of intrinsic film properties (higher Qbd values) together with improved uniformity. This kind of process is expected to be useful to obtain sound film quality control for ultra-thin oxide/oxynitride layer formation.

In some cases, combination of batch furnace process and single wafer process enables great film quality improvement and successful process performances, providing attractive solutions for some critical processes. One example is a ultra-thin gate oxynitride formation using furnace pure oxidation as a base oxide and single wafer plasma nitridation. Plasma nitridation on the top surface of the base oxide causes quite a large EOT reduction by about 3A without degrading bottom interface. This enables the use of comparatively thick oxide (13-15A) for the base oxide in order to obtain thin EOT values around 10-12A. It makes sense to use furnace process for the base oxide because it still has a advantage of excellent uniformity control and good stability than single wafer tools. Another example is the improvement of LPCVD films by adding plasma post treatment. This technique will enable extended use of furnace LPCVD system with well proven, good uniformity control and stability together with low cost of ownership(CoO).

Together with these technology challenges, and based on existing advanced vertical furnace FTPS(Fast Thermal Processing System), a new thermal processing equipment concept TELFORMULA (TEL Furnace for One-Station, Rapid-Thermal, Multi-Task Application) was introduced, providing a single chamber , multi-process capable, multi-wafer rapid isothermal processing platform with short cycle times. These challenges will continuously enable the furnace technology to meet both device development and manufacturing requirement for future devices.