Extremely Rapid Thermal Processing Using an Intense Hot Gas Stream

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Results are reported for a revolutionary approach to RTP developed under a DARPA sponsored Phase 1 SBIR program.[1] In this program analytic modeling and limited prior experimental results were used to investigate the feasibility of a process in which a hot gas stream delivers a very high heat flux to the wafer surface. This approach is markedly different than current oven type approaches in that (1) the hot gas temperature is much greater than the peak temperature reached by the wafer surface (~10 time peak temperature) and (2) the size of hot gas treatment area is less than the wafer size, see figure 1. Advantages with this approach are:

1. Very fast heating and cooling times, $>10^4$ ^{o}C/sec.
2. Heating independent of wafer emissivity (e.g., patterning, layers)
3. Peak wafer surface temperatures over a large range, $<400^{o}$C to $>2000^{o}$C.
4. Crystal defects can be eliminated.
5. May be used for silicon and non-silicon semiconductors
6. Very uniform processing regardless of wafer size.

This Hot Gas RTP (HG RTP) process can then meet advanced device manufacturing requirements for high peak temperature processing with very low thermal budget impact. This will enable applications such as: very shallow, very high conductivity junctions with abrupt boundaries; anneals of self-aligned structures without degradation of existing elements such as with high k gate dielectrics; and anneal of low temperature materials. Impurity doped, semiconductor structures may be produced by: anneal of implanted regions; diffusion of the impurity atoms from the hot gas stream through a mask pattern; or from a pattern deposited on the surface containing the doping impurity.

In this process, the wafer is scanned through the hot gas treatment that has a characteristic size of ~20mm diameter. The hot gas stream is generated using an atmospheric plasma. Peak temperature is controlled by the exposure time of an area of the wafer to the hot gas treatment area. It is evident that with sufficient heating power extremely rapid heating can occur. Not as evident is that equally fast cooling of the surface can be obtained by heating the wafer in a heat flux / exposure time regime that gives a large temperature differential through the thickness of the wafer. As a consequence, very rapid cooling can occur by the mechanism of thermal conductivity from the wafer surface into the bulk of the wafer.[2] Uniformity is obtained by multiple, off-set scans of the wafer through the hot gas treatment area. Throughput for exposure of 200mm wafers to a peak temperature ~1,200^{o}C can be >100 wafers/hr.

Under this program, analytic methods were developed for modeling the hot gas heating process. These methods included: wafer surface heating and cooling rates; diffusion under the time dependent conditions of multiple exposures of a wafer area to the hot gas stream; and full simulations of heat transfer to the wafer from a hot gas stream and cooling by heat transfer from the wafer to a wafer holder and process environment.

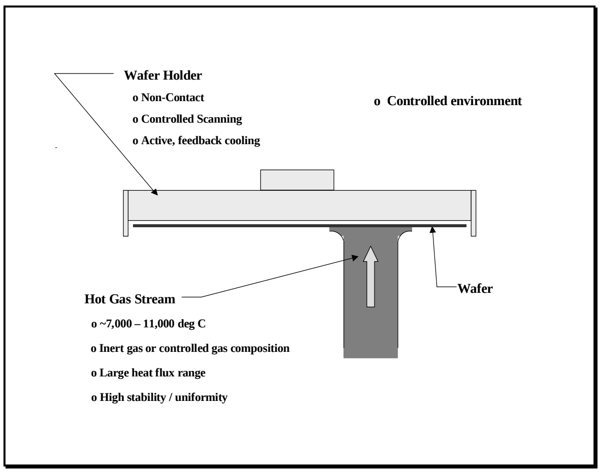

Figure 1. Concept of using a hot gas stream for extremely Rapid Thermal Processing.

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[1] "Materials and Tools for Heterogeneously Integrated Microelectronics - Novel Atmospheric Rapid Thermal Processing." Contract No. DAAH01-00-C-R202. Final Technical Report, February 2001.

[2] Patent Pending, PCT WO0135041, "Method for Rapid Thermal Processing of Substrates," L. D. Bollinger and I. Tokmouline