Supercritical Fluid Cleaning

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In order to produce functional semiconductor devices with reasonable manufacturing yield surface of the wafer must be maintained perfectly clean, i.e. free from particles, metallic and organic contaminants, throughout the entire production cycle. To accomplish this goal wafers are subjected to numerous cleaning operations making cleaning the most frequently applied processing step in advanced semiconductor manufacturing sequence. In cutting edge silicon technology requirements on cleaning are becoming more stringent with each technology generation. Wet, or liquid-phase, cleans are still sufficient to carry out overall goals of cleaning but with wafers featuring denser device geometries and increasing aspect ratios their efficiency is decreasing. Dry, or gas-phase, cleans are useful in surface conditioning applications but featuring orders of magnitude lower density than liquids they lack physical strength of the liquid ambient needed to dislodge some strongly adsorbed contaminants from the surface. Dry cleans can be modified to add element of momentum transfer to the cleaning action (e.g. cryogenic cleaning) but even then efficiency of the process is limited in the case of deep-patterned surfaces.

To work around inherent limitations of cleaning methods using liquids and/or gases, scientist and engineers are reaching to the fourth state of matter, i.e. to supercritical fluids. As Fig. 1 shows at certain pressure and

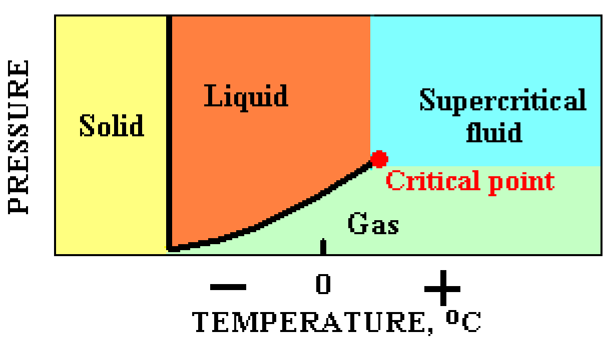

Fig. 1

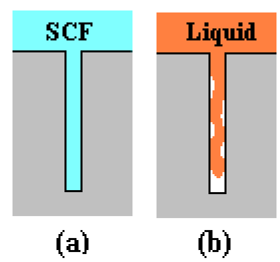

Fig. 2

temperature (critical point) either gas or liquid can be transformed into a supercritical fluid (SCF) which by combining some properties of liquids and gases displays distinct, quite remarkable properties. With density not much smaller than liquid and viscosity comparable with gas, supercritical fluid is very well suited for cleaning wafers with ultra-small geometry structures. As SCF features negligible surface tension a complete penetration of very high aspect ratio structures can be accomplished (Fig.2a). This is in contrast to liquids which due to significant surface tension are not able to completely penetrate such ultra-small geometries (Fig.2a). The problem with supercritical fluid generation is that while temperatures at which critical point can be reached are fairly moderate (typically below 100 ^{o}C) pressures, depending on material, can be as high as 200 atm.

Very early in the process of adoption of SCFs in semiconductor manufacturing carbon dioxide, CO_2, has emerged as a candidate the best suited for conversion into a supercritical fluid. This is because CO_2 reaches critical point (Fig.1) at low temperature of 31 ^{o}C and reasonable pressure of 79.6 atm. In addition CO_2 is a fairly benign, recyclable, and readily available gas. SuperCritical CO_2 ($SCCO_2$), by itself is not a cleaning agent, but can be mixed with organic co-solvents such as propylene carbonate, acetyl acetone and others needed to achieve sufficient solvating potential of the mix. The role of CO_2 in the mix is to carry the co-solvent to the areas that must be cleaned and to bring it back along with products of cleaning reaction. All these features make ($SCCO_2$) cleaning an effective alternative to conventional cleaning methods used in cutting-edge semiconductor processing including MEMS device manufacturing.