Evolution of Wafer Temperature Control in Ion Implantation

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The rapid and continuous expansion of electronic devices in our lives, with an emphasis on wireless and handheld technology has placed new challenges on semiconductor manufacturing. Device technology has evolved demanding smaller transistors with higher performance. Improving device performance and lowering leakage current, has become an important area of focus for our customers. Ion implantation can inadvertently contribute to device leakage through latent implant damage, and as such, our equipment has to evolve to meet the new requirements with new solutions for damage control.

Traditionally, process control in ion implantation was focused on the primary ion beam variables of ion species, energy, dose, and beam current. Wafer level process control was limited to crystallographic orientation of the wafer to control channeling, and providing adequate charge control. A second order consideration was to control wafer temperature. The wafer absorbs power equal to the product of beam current and beam energy, a value that can be a few thousand watts. Unchecked, this will result in increasing wafer temperature. Wafer temperature has been loosely controlled using process cooling water and chillers, predominantly on high energy and high current implanters. Many medium current implant steps required little cooling due to low power.

The motivation for controlling wafer temperature was to protect the photoresist mask used to delineate the areas to be implanted. The photoresist material is analogous to plastic; it can flow and melt at temperatures exceeding just over 120°C. If the wafer temperature was maintained at < 100°, little consideration was given to the absolute temperature, which could range from room temperature to near the maximum allowed. As a result, the topic of wafer temperature control was limited entirely to ways of preventing burning or melting of photoresist without consideration to more complex crystallographic effects. **"*Just don't burn the photoresist*"**, became the rule of the day. Ion implantation courses and materials were dedicated to the concept of photoresist integrity under high power or high dose ion implantation. Photostablization products were marketed to improve the stability, a market space where Fusion and Axcelis enjoyed success. Little regard was give to the subtle material science effects occurring within the silicon during implantation, most notably defects induced in the silicon crystal.

Controlling these defects has opened an area of process science we define as Damage Engineering. Damage Engineering is defined as the purposeful characterization and control of the nature and location of ion implant damage using dose rate and wafer temperature control. The dominant factors establishing latent damage from ion implantation are ion mass, ion dose, instantaneous dose rate (beam current per unit area), and wafer temperature. Ion mass and ion dose are controlled by the device designers and outside of the control of the implant process engineer. Typically, the dose rate is maximized for given conditions, as the highest beam current (dose rate) is the condition of maximum throughput, the ideal manufacturing condition. Notably, Axcelis has a competitive advantage in dose rate due to our high-density spot beam technology, compared to a low-density ribbon beam. The last significant parameter to control is therefore temperature, and as stated previously, wafer temperature was not well controlled historically.

With the introduction of wafer temperature control on the Optima HDx in 2007, Axcelis became the first mainstream implant manufacturer to implement closed loop temperature control on a production implanter. The first application was to match the damage characteristics of the competitors ribbon beam systems. Later, we leveraged this technology into a competitive advantage for damage engineering using sub-zero implants, where our high dose rate allowed us to achieve results similar to our competitor but at warmer temperatures (-50°C vs. -100°C), a clear advantage in high volume manufacturing. We are currently investigating the potential benefits of damage engineering for medium current and high-energy applications across a wide range of temperatures from sub zero to hundreds of degrees centigrade.

The number of applications or technologies requiring hot or cold implant temperatures in the future is yet to be determined, but we have ushered in a new era in ion implantation technology and process control.

Wafer temperature control has become a primary factor for process optimization and control. The days of *"**Just don't burn the photoresist"*** are behind us forever.