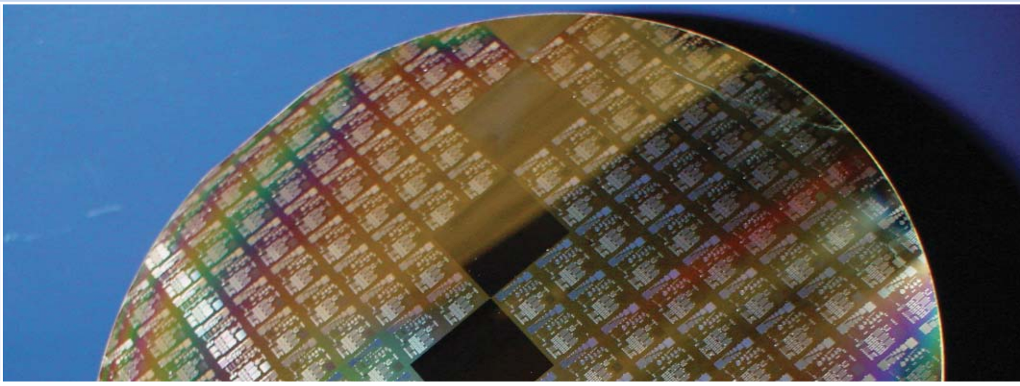
Application Report:

LASER ACTIVATED VAPOUR PHASE PROCESSES FOR NANOELECTRONIC FABRICATION



Excimer Laser

Why Excimer Laser?

- Short Wavelength necessary for molecule dissociation
- Wavelength of 193 nm suitable for a wide range of process gases

Why Coherent's Excimer?

- Ease of use
- Very stable operation
- Repeatable results
- Adjustable repetition rate and pulse energy

In modern silicon semiconductor technology the thermal treatment of the wafers during the fabrication process has become one of the most critical issues. Many process steps require comparatively high temperatures above 800 °C to achieve optimum results. Heating a silicon wafer up so far causes problem for several reasons.

First the minimum feature sizes and therefore the distance between highly doped regions in state of the art electronics is only 45 nm and the roadmap of semiconductors predicts further shrinking in the next future. Fig. 1b illustrates what happens to a 10 nm thick highly boron doped layer in silicon after a thermal treatment of only 10 minutes at 800 °C.

Indicated by the colors it is clearly visible that the dopand atoms have been redistributed by diffusion and the effective thikkness of the layer is now more than 30 nm with a huge gradient at both sides.

If this had happened to highly doped regions on a wafer during electronics fabrication, the devices build from this structures would not reach the aspired performance or fail completely. Fig. 1c on the other hand side shows the doping profiles after a 10 minute 700 °C step. The doping profiles remain almost unchanged. So from this point of view a reduction of process temperatures below 750 °C would be desirable.

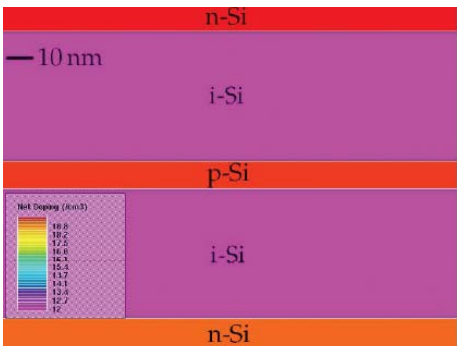


Fig. 1a

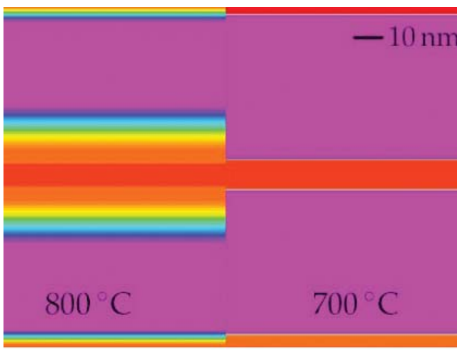


Fig. 1b *Fig. 1c*

Fig. 1:
Dopand diffusion from a 10 nm thick highly boron doped layer (1a) during an 800 °C temperature step (1b) and a 700 °C temperature step (1c).

Superior Reliability and Performance

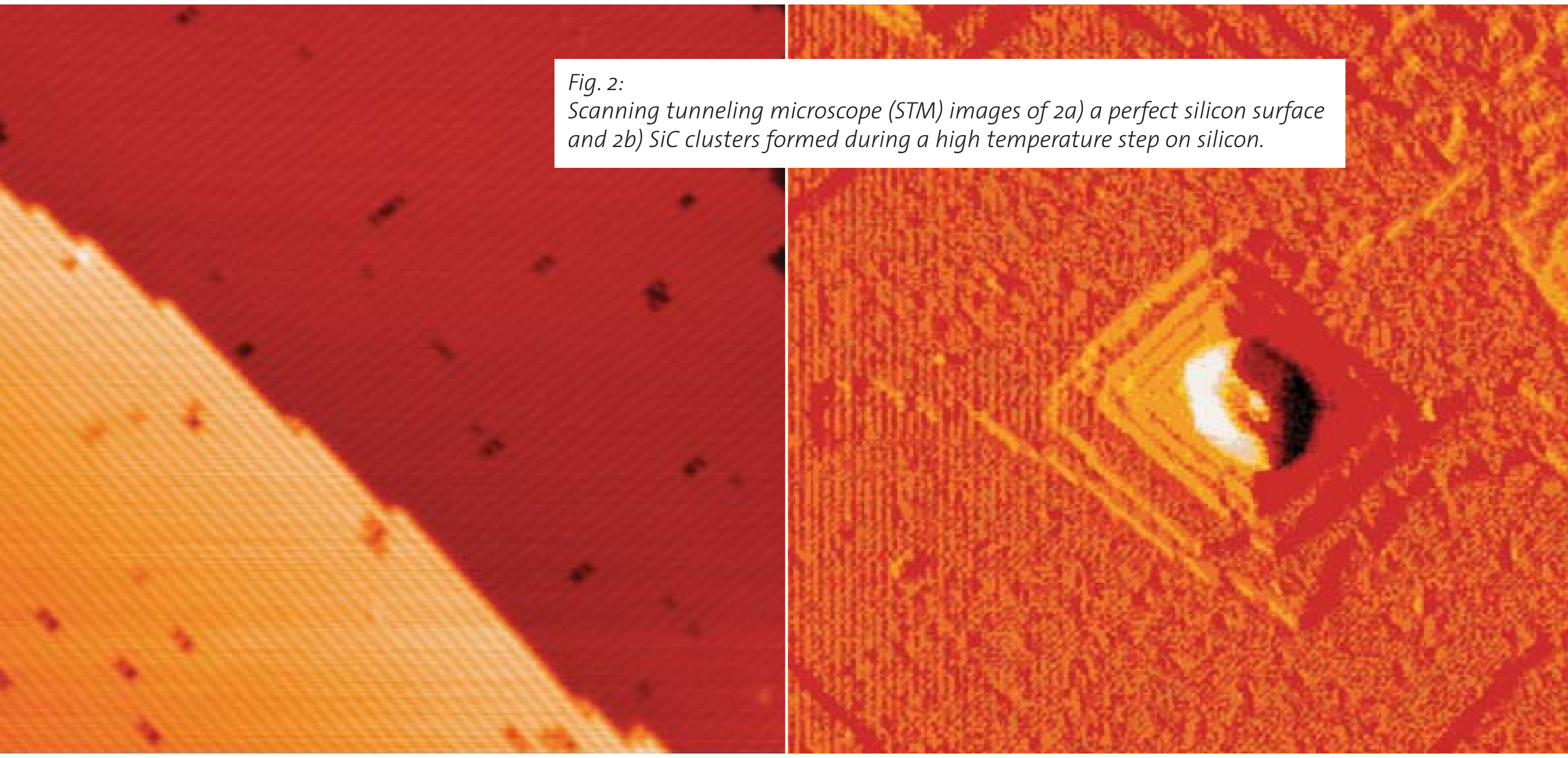


Fig. 2:
Scanning tunneling microscope (STM) images of 2a) a perfect silicon surface and 2b) SiC clusters formed during a high temperature step on silicon.

Fig. 2a 46 nm x 46 nm

Fig. 2b 93nm x 93 nm

Another effect caused by high temperatures is the formation of silicon carbide clusters on the surface of a wafer. Fig. 2a shows a scanning tunneling microscope (STM) image of a perfect clean silicon surface. The dots visible are the single silicon atoms. Fig. 2b shows a STM image of a sample which had carbon on its surface and was treated with a high temperature step. The pyramid like looking structures are silicon-silicon carbide clusters formed during this process step. Their size exceeds up to 20 nm and therefore a device in this place with a feature size of only 35 nm will fail. The carbon originates mainly from organic impurities or microorganisms which are present everywhere in the environment. The formation of silicon carbide begins at temperatures above 800 °C. Therefore again a reduction of the process temperatures below 750 °C and especially a carbon cleaning step at low temperatures would be desirable.

Most vapour phase processes are known for their demand on wafer temperatures. The temperature is necessary to activate the desired reaction of the gas molecules with the wafer surface or contaminations on it. In many cases, the limiting part of the reaction is the decomposition of the gas molecules in highly reactive parts. The approach followed here is to use the energy provided by a laser beam to dissociate the molecules in the vapour phase and create radicals. Therefore the targeted reaction will take place at much lower wafer surface temperatures.

We combined a Coherent Excimer Laser (wavelength 193 nm) with an ultra high vacuum process chamber with a multi gas inlet equipped for the use with up to four process gases.

In principle there are two possibilities to guide the laser beam with respect to the wafer surface: normal or parallel. Guiding the laser beam normal to the surface means interaction with the surface and local heating. As we want to use the beam only to activate the molecules in the vapour phase, the most desirable solution is guiding the beam parallel to the substrate but in very close distance. Fig. 3 illustrates the two possibilities while the parallel beam guide on the right hand side is the realized one.

To provide the possibility of heating the substrate decoupled from the laser energy a RTP lamp heater is adapted to the chamber. This allows to adjust the substrate temperature precisely and with short heating ramp durations.

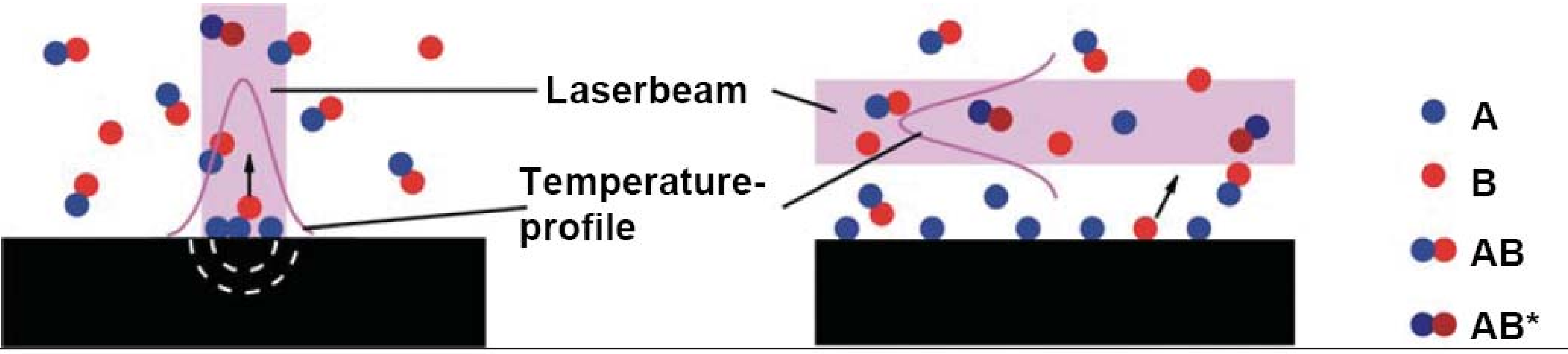


Fig. 3: Possible beam guide solutions

This equipment was used to improve vapour phase cleaning processes. Cleaning in this case means the removal of the native oxide (which grows on pure silicon at room temperature just by exposure to air) and organic impurities (which cause silicon carbide cluster formation).

Silicon dioxide SiO_2 can be removed from the surface by heating the wafer in germane (GeH4). The GeH_4 molecule is split on the hot surface and Ge reacts with SiO_2 to GeO and SiO, both volatile in an UHV environment. This reaction normally needs a minimum surface temperature of the wafer of 700 °C.

Activating the GeH_4 molecule by the laser, which means splitting a hydrogen radical from the molecule, reduces the minimum reaction temperature to 600 °C. With a GeH_4 partial pressure of 10^{-4} mbar an etching rate of 0.5 Å/min was achieved. Furthermore hydrogen radicals H* generated by splitting hydrogen from the GeH_4 molecule by laser activation removes also carbon at temperatures above 550 °C.

Another possibility to clean silicon substrates from organic impurities is heating in oxygen atmosphere and thereby "burning" it to carbon oxide. The laser energy can dissociate the oxygen molecule O_2 into two oxygen radicals O*.

These radicals are much more reactive than the molecules. By secondary ion mass spectroscopy (SIMS) measurements we proved that the removal of carbon by activating oxygen with the laser takes place even at room temperature. The partial pressure of oxygen necessary for this reaction is only 10^{-4} mbar and the process time is less than one minute.

The influence on the crystal quality of epitaxial silicon layers grown on such carbon free surfaces was determined by fabricating so called triangular barrier diodes (TBD) on the cleaned wafers. The breakdown behavior of these test structures is very sensitive to the carrier lifetime in the epitaxial grown layers. Point defects in the crystal reduce the carrier lifetime, the breakdown behavior can be used to derive the crystal quality. The TBDs fabricated on the cleaned wafers showed a behavior similar to those expectable from defect free, i. e. ideal, layers.

The decoupled combination of an Excimer Laser with an RTP heater has proved to be an excellent method to reduce the total thermal budget in modern semiconductor processing. The concept is suitable for many vapour phase processes and due to its modular assembling it is easily adaptable to existing processing tools.

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