

Gas Flow Rate and Composition

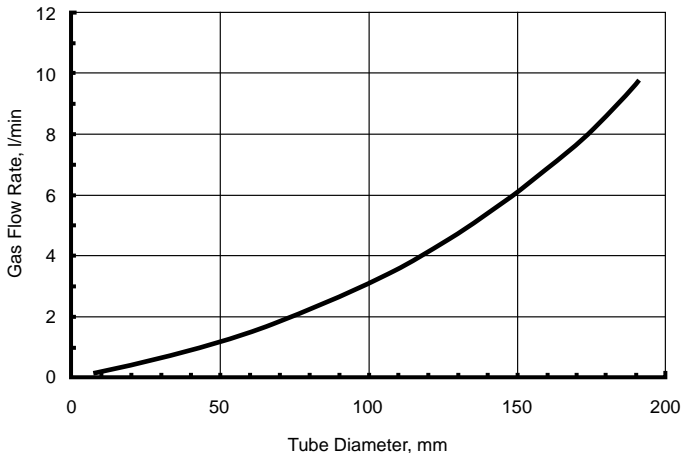
Introduction

Selecting the proper gas flow rate and gas composition for a given diffusion system and diffusion process is critical to the successful performance of the BoronPlus[®] and PhosPlus[®] dopant sources. This bulletin was therefore prepared to provide the diffusion engineer with the appropriate general guidelines necessary to select the parameters which will give the best results for his system. The bulletin also describes a procedure which eliminates the need for a separate low temperature oxidation cycle when BoronPlus sources are used as the dopant source.

Gas Flow Rate

The gas flow rate for a given diffusion system is primarily determined by the diameter of the diffusion tube. Typical flow rates can be selected from the curve plotted in Figure 1.

Figure 1: Gas Flow Rate vs. Tube Diameter



Generally, the gas flow rate should be as low as possible, but high enough to prevent air from backstreaming down the diffusion tube. Exceptionally high flow rates are normally avoided during the time at the deposition temperature since high rates tend to produce non-uniform sheet resistivities at the gas inlet (source) end of the boat. This is because the rapidly-flowing gas carries the B₂O₃ or P₂O₅ away from the diffusion source and down the diffusion tube before it has a chance to deposit on the silicon wafer located next to the source.

Backstreaming of room air down the diffusion tube must not be allowed to occur or non-uniform sheet resistivities will be observed at the handle (load) end of the boat. This is because the excess oxygen grows a relatively thick oxide film on the silicon wafers which masks off the deposited B₂O₃ or P₂O₅ from the diffusion source. One way in which backstreaming can be significantly reduced in many diffusion systems is to use a high gas flow rate (10-15 l/min) whenever the end cap is off the end of the tube (i.e., during insertion and removal of the boat). The flow rate should then be turned down to the recommended rate when the end cap is replaced.

A high gas flow rate, however, is not very effective in preventing backstreaming in large diameter diffusion tubes (i.e., 200 mm). It has been reported that the nitrogen tends to flow to the top of the tube and the air tends to backstream down the bottom of the tube, regardless of the flow rate. Consequently, sufficient time should be allowed at the insertion temperature after the tube is closed so that the nitrogen can purge the tube of backstreamed air before ramping to the deposition temperature. Also, since cantilever systems are usually used with large diameter tubes, care should be taken to ensure all excess areas in the end cap around the cantilever arms are closed.

Gas Type

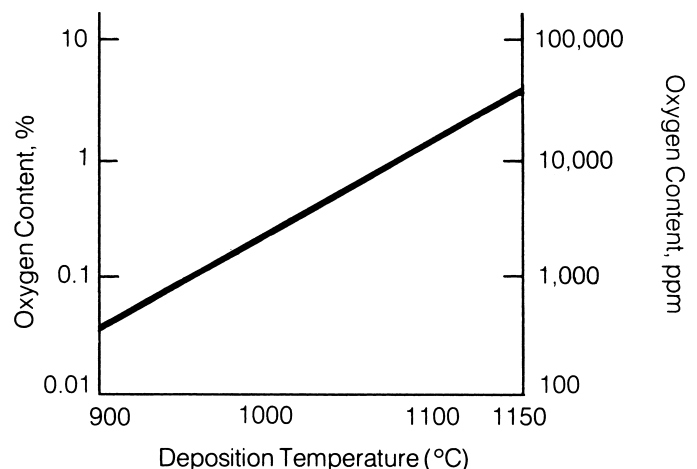
Most diffusion systems use nitrogen as the carrier gas in the diffusion tube. Some diffusion engineers prefer to use argon gas when depositions are to be made above about 1050°C because argon is an inert gas and does not react with the silicon surface to cause nitride pitting.

Gas Composition

The proper use of oxygen with the selected carrier gas can have a significant effect on silicon surface damage. The amount of oxygen that must be blended into the carrier gas tends to increase with increasing deposition temperature. Generally, some oxygen must be used at temperatures above about 1000°C while little or no oxygen is required below this temperature. Figure 2 can be used as a guide to select an oxygen content which normally minimizes silicon surface damage when depositions are being made with BoronPlus or PhosPlus sources.

Care must be taken not to use too much oxygen during the deposition cycle. If this occurs, an oxide film will grow on the silicon surface that is thick enough to mask off most of the B₂O₃ or P₂O₅, resulting in non-uniform doping of the silicon wafer.

Figure 2: Recommended Oxygen Content of Carrier Gas vs. Deposition Temperatures



Some phosphorus emitter diffusion processes done with gas-type dopant sources often include an oxidation of the silicon surface immediately following the phosphorus deposition. This can also be done with the PhosPlus solid source system if the oxidation is done with dry oxygen. Dry oxygen can be used with the PhosPlus sources at any temperature since oxygen has no effect on the sources. However, the oxidation cannot be done at the deposition temperature with wet oxygen or with steam since the moisture will quickly deplete the PhosPlus sources of available P_2O_5 .

Removal of Boron Silicide Using LTO Cycles:

Boron silicide is the thin, metallic compound that forms under the deposited glassy film during a boron deposition cycle. Synonymous names are boron-rich phase, boron-silicon phase and silicon stain. The phase is insoluble in HF, and it can be detected after the HF etch by the hydrophilic (wetting) silicon surface compared to the normal hydrophobic (non-wetting) surface of undoped silicon wafers.

Boron silicide is beneficial to silicon processing because it produces uniform sheet resistivities in the doped silicon slices and because it can be used as a limited source of boron in certain drive cycles. However, this phase is removed most of the time before subsequent processing steps are taken so that it does not become a source of additional problems later.

The Traditional LTO Cycle: The most common method of removing the boron silicide phase is to use the low temperature oxidation (LTO) cycle. This technique involves stripping the glass from the doped silicon slices and then re-inserting them into the diffusion furnace without the sources being present. Holding the silicon slices at $800^{\circ}C$ for 20-30 min in steam or in wet oxygen is usually sufficient time to oxidize a thin layer of this phase. The new oxide layer is then etched off the silicon surface in dilute HF before continuing the processing of the silicon wafers. The LTO cycle tends to raise the sheet resistivity, but it does not normally destroy the uniformity of the doped silicon slices.

The In-situ LTO Cycle: An important variation of the above LTO cycle that can be used in the presence of the BoronPlus sources is to start oxidizing the silicon with pure oxygen either during the cool-down portion of the deposition cycle or after the boat has reached the removal temperature [1]. Fig. 3 shows schematically how the in-situ LTO eliminates a processing step during a boron deposition cycle.

Although cooling in oxygen has eliminated the need for a subsequent separate LTO process, it can affect the uniformity of the doped silicon wafers. This is because the oxygen must diffuse through the deposited glass before it can oxidize the boron silicide, and any non-uniformity in the thickness of that glass will affect the rate of the oxidation of the silicon surface below it. Experience has shown that this process usually works very well for high temperature isolation and pnp emitter processes, but it is not always acceptable for low temperature base diffusions where uniformity is much more important.

Wet oxygen or steam cannot be used in this modified LTO process since the moisture will quickly deplete the BoronPlus sources of available B_2O_3 . However, dry oxygen can be used at any temperature, since oxygen has no effect on the sources. In this case, the next run will be the same as the one that has just been completed.

Gas Composition – Moisture

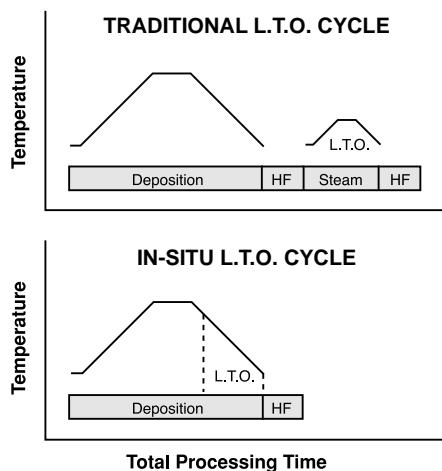
Uncontrolled amounts of moisture entering the diffusion tube can cause silicon surface damage, non-uniform doping of the silicon, etc. However, when moisture is formed in the diffusion tube at very low levels and in a controlled manner in the presence of GS-126 BoronPlus sources as described in Product Bulletin 310, uniformity of doping can be improved and excellent devices can be produced. The work done at the University of California, Berkeley showed how the technique can be used to produce p-type source/drain diffusions in a CMOS IC that are equivalent to those produced with ion implantation [2].

Conclusion

Optimum doping results are obtained from the BoronPlus and PhosPlus sources when the proper carrier gas flow rates and carrier gas oxygen concentrations are selected. The ability to use the sources in the presence of oxygen provides greater flexibility during the deposition process since oxygen has no effect on their performance. This aspect is particularly useful with the BoronPlus sources, where they may be used during an in-situ LTO cycle to oxidize the boron-silicon phase. The in-situ LTO completely eliminates the need for a separate LTO step and can result in significant savings.

For more information on this Product Bulletin or on the BoronPlus and PhosPlus dopant sources, contact the Planar Dopants Team: www.techneglas.com

Figure 3: In-situ LTO vs. Traditional LTO with BoronPlus Sources



"Information contained herein is derived from in-house testing and outside sources and is believed to be reliable and accurate. TECHNEGLAS, Inc., however, makes no warranties, expressed or otherwise, as to the suitability of the product or process or its fitness for any particular application."

References:

1. J.E. Rapp, "The Planar Diffusion Technique", Semicon Technology Asia 1998/9, Nordica International. 3.F Block B, Quarry Bay, Hong Kong, p. 33.
2. R. Alley, P.K. Ko and K.Voros, "Characterization of the BoronPlus Planar Dopant Source Moisture Enhanced Process", Thesis at University of California, Berkeley, Sept 18, 1986. Memorandum No. UCB/ERL M86/75.

BoronPlus and PhosPlus are registered trademarks of TECHNEGLAS, Inc.