Increased Yield Using PDS® Products Grade BN-975 with Hydrogen Injection

The purpose of the hydrogen injection process is to increase die yield per wafer. This is accomplished because the effects associated with the hydrogen injection process. These effects are 1) improved uniformity across the wafer, across the run and run to run; 2) control of defects such as oxidation induced stacking faults and point defects simultaneous to the deposition process. The successful implementation of the hydrogen injection process has been shown to produce higher yields than other methods of boron deposition, helping to improve process cost effectiveness. PDS Products BN-975 wafers with hydrogen injection also offer flexible applicability that can produce sheet resistivities of more than 500 Ω/ □ to less than 10 Ω/ □.

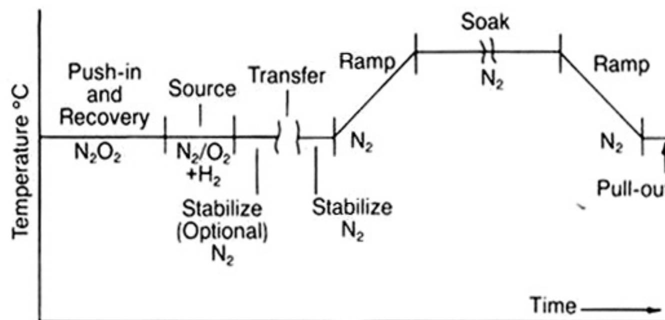
Temperature Range

High Temperature Processing (>975°C): PDS Products BN-975 with two-step hydrogen injection offer flexible applicability for process temperatures of more than 975°C. The two- step hydrogen injection process can be used for deep isolation diffusions, bases for power transistors, bases for linear polar devices and other applications. It allows one set of sources to be used for all boron processes, regardless of temperature.

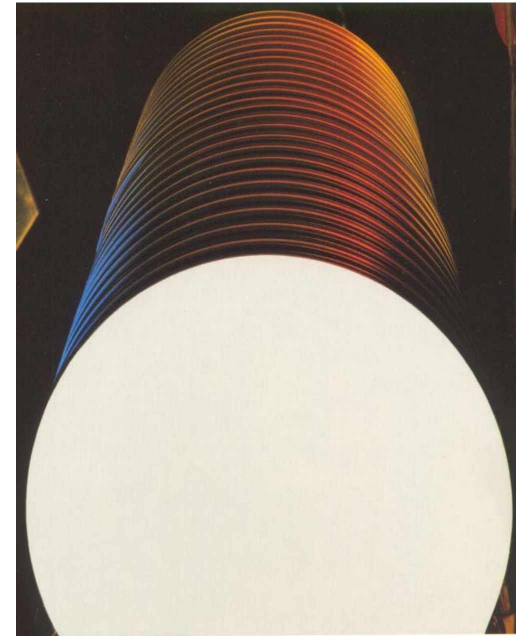
Process Outline for High Temperature BN-975 2-Step H_2 Injection

Step	Ambient	Time	Function
Recovery	N_2/O_2 50%/50%	15 Min.	Thermal Equilibrium Thin Oxide Growth
Source	Add H_2 1-4% Vol	1-4 Min,	Dopant Glass Transfer
Transfer	Room	30 min. (20 Min. Preferred)	Separate Si Wafers to Quartz Boat for High Temperature Soak
Soak	N_2 (100%)	Variable	Defect Control Resistivity Target
Deglaze	10:1 HF	2 Min	Remove Unreduced Glass
Low Temperature Oxidation (LTO)	100% O_2	20 Min.	Remove Si-B Layer and defects.

Figure 1. Process Cycle for High Temperature BN-975 2-Step H_2 Injection



Technical Bulletin



Advantages of PDS Products

Extreme flexibility that allows application to many device structures, thereby eliminating capital expense in device conversion.

Improved yields by gettering oxidation induced stacking faults and improved uniformity across the wafer, across a run and from run-to-run.

Precision chemical principles make for predictability and repeatability through the controlled introduction of moisture in the diffusion tube, even at temperatures as low as 750°C.

Moisture modulation of the vapor pressure of the B_2O_3- HBO_2 system causes a rapid flux of gas, creating excellent uniformity and allowing a damage control mechanism to be established simultaneous to the deposition process.

Successful application of the PDS® hydrogen injection process throughout the semiconductor industry.

A trained staff is maintained to assist in all technical needs and support.

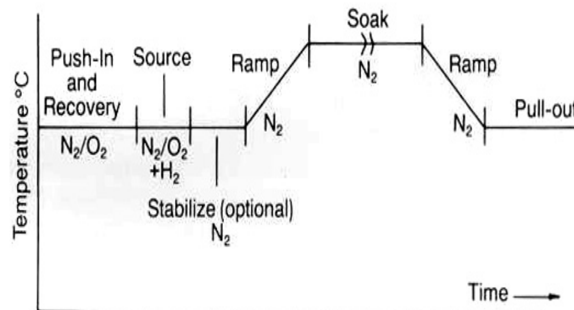
SAINT-GOBAIN CERAMICS

Low Temperature Processing (<975°C): The hydrogen injection process at low temperatures can be used for shallow structures such as bases for high-speed high-density bipolar devices, MOS source-drain and CMOS p-well applications. Similarly, this process can also be used for deep isolation diffusions, bases for power transistors, and bases for linear bipolar devices, guard rings, channel stops and other applications.

Process Outline for Low Temperature BN-975 Single Step H2 Injection

Step	Ambient	Time	Function
Recovery	N_2/O_2 50%/50%	15 Min.	Thermal Equilibrium Thin Oxide Growth
Source	Add H2 1-4% Vol.	1-4 Min,	Dopant Glass Transfer
Soak	N_2 (100%)	Variable	Defect Control Resistivity Target
Deglaze	10:1 HF	2 Min	Remove Unreduced Glass
Low Temperature Oxidation (LTO)	100% O_2	20 Min.	Remove Si-B Layer and defects.

Figure 2. Process Cycle for Low Temperature BN:H_2 2-Step Injection



Processing Outline

Push in and Recovery

During the recovery step, source boats stacked with BN-975 wafers and silicon wafers are pushed into a diffusion tube. The tube is then allowed to establish ambient equilibrium. This step is generally performed in an ambient of 50% N_2 and 50% O_2 at 750°C-850°C. Typical total flow rates are 6–10 slpm, depending on the combination of source wafer and process tube diameters used. The N_2/O_2 ambient during the recovery step grows a thin layer of SiO_2 in the mask window regions. This thin layer of SiO_2 masks B_2O_3 diffusion during the push in cycle, thus minimizing or eliminating the sheet resistivity gradients due to the first wafer in being the last wafer out.

Sourcing

The function of the sourcing step is to rapidly transfer dopant glass from the BN-975 wafer surface to the surface of the silicon wafer. This is accomplished by the controlled injection of up to but no greater than 5% (by volume) H_2 gas into the N_2/O_2 diffusion tube ambient. Good safety practice is to inject the H_2 into a heated process tube (above 750°C) and in the presence of excess O_2 to ensure all the H_2 is consumed to form water vapor. The introduction of hydrogen into the diffusion tube causes a hydration reaction converting B_2O_3 in to HBO_2 (metaboric acid) at essentially the same instant throughout the diffusion tube. The hydrogen gas flow is maintained between 1 min. and 4 min. depending on how much dopant glass is desired. During the sourcing step, an extremely rapid glass transfer occurs due to the higher partial pressure of the HBO_2 species as compared to the pressure of B_2O_3. There is sufficient pressure of HBO_2 to allow transfer as low as 750°C.

A typical hydrogen injection cycle will produce 500-1000 Å of soluble HBO_2 dopant glass with only one min. of H_2 injection and 4% hydrogen. This rapid flux of dopant glass initiates the damage and defect control mechanism.

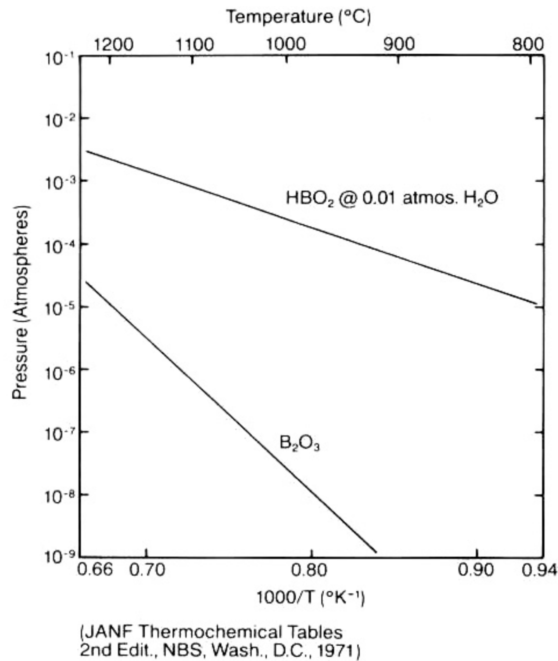
At the end of the source step, both H_2 and O_2 are shut off. Nitrogen flow is increased to equal the total flow during the recovery step. Gas control panels are available from several manufacturers specifically for the hydrogen injection process. Mass flow controllers are also available that allow for constant flow starts. Constant flow is absolutely imperative in order to avoid the problems associated with “hard” starts (the buildup of pressure in the gas line in which a large amount of gas is initially released until the mass flow controller reacts) or “soft” starts (associated with older gas control units that allow only a gradual rise of gas flow that prevents full flow from being reached only during the last few seconds of the one min. H_2 injection cycle, and not the necessary full duration).

Forming gas, a mixture if N_2/H_2 may be used as an alternative to 100% H_2 gas. During sourcing, the nitrogen gas flow must be reduced by the amount of N_2 gas contributed by the foaming gas so that the N_2/O_2 ratio during sourcing remains 1:1. The forming gas flow should be at a level in which H_2 volume is less than 4% of the total flow. In other words, all levels must be correlative to those present in regulated H_2 use.

Regardless of the method of hydrogen injection chosen, it is important that gas flows are accurate and reproducible and that H_2 volume percent levels are below 4% of the total N_2/ O_2 ratio and in excess O_2.

After sourcing, a 10 min. N_2 purge may be performed to remove latent moisture before proceeding to the next process step.

Figure 3. Partial Pressures of the B_2O_3/ H_2O System



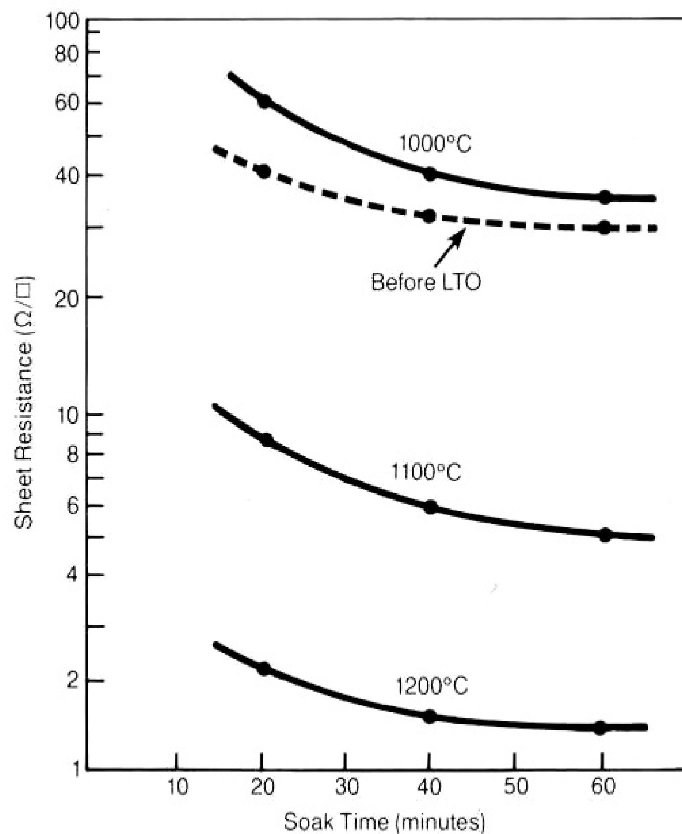
Soak

During the soak step, the dopant glass which is uniformly coating the silicon wafers undergoes a reduction reaction in the ambient which results in the formation of a thin insoluble layer of silicon-boride, Si-B, at the silicon surface. The Si-B layer serves traps crystal damage at the silicon/ SiB interface through a strong gettering action. In essence, the function of the soak step is to control damage while obtaining the targeted sheet resistivity.

High Temperature Soak Step: The soak step is initiated by the separation of the silicon wafers from the BN wafers by transferring the silicon to another carrier for the subsequent high temperature (975°C+) soak step. The time between when the boat is pulled and when the silicon wafers are pushed into the soak furnace should be kept to less than 30 min. (ideally, less than 20 min.). By not exposing the BN-975 wafers to higher temperatures, the sources can be expected to have longer lifetimes. Consequently, this type of processing allows increased flexibility as the BN boat may then be used in another deposition process in a different tube while the first silicon lot is undergoing soak. One set of sources can be used for all boron processes, regardless of temperature.

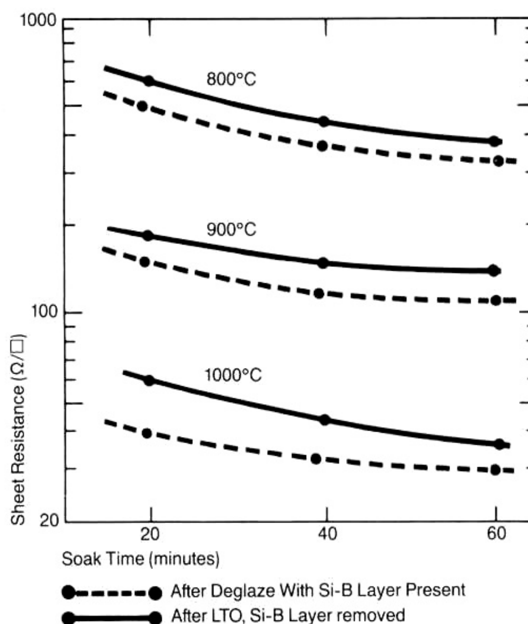
Pushing the silicon wafers coated with B_2O_3 glass into a furnace tube in which the N_2 flow rate has been adjusted to a rate equal to that of the combined N_2 and O_2 flow rates during the previous recovery and sourcing cycles. Once the desired rate has been achieved, ramp to the soak temperature and soak until the desired resistivity is obtained (see Figure 4A).

Figure 4A. Sheet Resistance vs. Soak Time for High Temperature Applications



Low Temperature Soak Step: The soak step is initiated by turning off the H_2 and O_2 gas flows at the end of the sourcing step, adjusting the N_2 flow rate to a rate equal to that of the combined flow rates of the N_2 and O_2 during the previous recovery and sourcing cycles. Once the desired rate has been achieved, ramp to the soak temperature and soak until the desired resistivity is obtained (see Figure 4B).

Figure 4B. Sheet Resistance vs. Soak Time For Low Temperature Applications



To obtain the best results, it is recommended that the soak cycle be at least 30 min. in length to allow sufficient time for the damage control mechanism to take place and to minimize resistance variation caused by inconsistent pull cycles in furnace unloading. Upon completion of the soak cycle, it is recommended that the furnace be ramped down before pulling the wafers. The use of a controlled environment such as a “white elephant” or a tube extension is beneficial where available as it allows cooling of the wafers under a controlled, moisture- free ambient. This retards the hydration of the un-reacted B_2O_3, which appears as hazing on the surface of the silicon wafers. It is recommended that the time between pulling the wafers and the first deglaze step be less than 30 min.

Low Temperature Oxidation (LTO)

The function of the LTO step is to oxidize the Si-B layer and a thin layer of Si below it. Oxidizing this thin Si layer will immobilize most of the crystal defects in the oxide. A steam or O_2 ambient is typically used to cause the rapid oxidation of the Si-B layer and it’s silicon interface region before harmful propagation of the defects into the silicon can occur. See LTO Technical Bulletin for additional information.

Saint-Gobain Ceramics
Boron Nitride Products
168 Creekside Drive
Amherst, NY 14228-2027
Telephone (Toll Free): 1-877-691-2001
Fax: (716) 691-2090

www.bn.saint-gobain.com

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