Issues with Transferring PureB CVD from an Epitaxial Reactor to a Furnace System

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Abstract— In order to transfer the CVD process from a single-wafer epitaxial reactor to a batch furnace system, several issues have to be considered. The main process issue is that PureB deposition is highly-selective, depositing only on silicon and not silicon dioxide. Silicon surface has to be free of native oxide and oxidation must be prevented during wafer loading. In addition, the use of hydrogen as a carrier gas, under atmospheric pressure in the current epitaxial reactor CVD process, is a significant safety consideration for use in a batch furnace.

Index Terms—PureB, ultrashallow junction

I. INTRODUCTION

ULTRASHALLOW junctions have been successfully achieved by the deposition of pure amorphous boron layers (PureB) [1]. The high gradient in boron concentration at the silicon surface and the total amount of boron atoms in the PureB layer provides an “infinite” source of dopants. The eventual junction depth is determined by the thermal diffusion of boron into silicon at the given process temperature. Since this process is essentially defect-free, unlike the standard ion-implantation process, transient enhanced diffusion of boron is effectively avoided. As such, several high-performance photodiode detectors using the PureB layer have been developed [2-4].

The current process for PureB deposition has been to perform the deposition in a commercial single-wafer epitaxial chemical vapor deposition (CVD) reactor under atmospheric pressure condition using diborane and hydrogen as the source gas and carrier gas respectively. However, this is not feasible for high-throughput industrial applications where a batch furnace system is preferred.

Although CVD processes in an epitaxial reactor share many features with furnace processes, a number of issues have to be considered in order to transfer the CVD process from a single-wafer epitaxial reactor to a batch furnace system. In this paper, several of these issues will be examined. In particular, the most critical process limitation is with regards to the selectivity of PureB deposition. This work enables a clearer analysis towards a possible furnace compatible process condition.

II. EQUIPMENT

In the commercial single-wafer epitaxial CVD reactor, the wafer is horizontally placed on a rotating graphite susceptor with gas flow parallel to the wafer surface. As graphite is porous and might trap reactant or product gases, or it might react, resulting in carbon-incorporated into the deposition layer, silicon carbide (SiC) coating is applied to the graphite present in the reactor. The epitaxial CVD reactor is a cold-wall reactor, therefore PureB does not readily deposit on the quartz reactor chamber. In terms of operating pressure, the reactor can operate either at atmospheric pressure or reduced pressure.

In the epitaxial reactor, wafer is first loaded into a load-lock, which is subsequently pumped down before the wafer is transferred to the reactor chamber by automatic wafer transfer arms. Before every process run, a HCl-clean is performed in the reactor chamber. The gases used in the epitaxial CVD reactor are extremely pure. Carrier gases, like hydrogen or nitrogen, pass through a purifier and have impurity levels below 10ppb. Therefore, PureB deposition takes place under conditions that are almost water and oxygen free.

In addition, to ensure that the silicon surface is native oxide free, a pre-bake step is performed. Figure 1 shows a simple schematic of a single-wafer epitaxial reactor [5].

In the common horizontal batch furnace CVD systems, quartz boats are utilized to load and unload a batch of wafers...
into the quartz process tube. The entire process tube is surrounded by heating element, resulting in its hot-wall nature. The deposition of PureB on the process tube is unknown and has to be considered. In terms of operating pressure, the furnace system can also operate either at atmospheric pressure or reduced pressure. Figure 2 shows a simple schematic of a horizontal batch furnace system [6].

In a batch furnace system, a load-lock is normally not used. Wafers are loaded directly into the quartz process tube under atmospheric pressure condition at a load-in temperature of around 600-800°C. Therefore, a critical difference between a furnace system and a single-wafer epitaxial reactor is that the impurity levels of water and oxygen in the furnace are not as low as in the epitaxial reactor.

Processing in single-wafer epitaxial reactors is usually costly and energy-intensive. Not only is the throughput and utilization of the reactant gases low, additional time is lost to clean the reactor chamber before deposition and in the pre-bake step. Table 1 shows a comparison of typical CVD process flow in a single-wafer epitaxial reactor and a batch furnace system.

### III. PROCESSING ISSUES

Currently, PureB is deposited in the epitaxial reactor at atmospheric pressure with a range of temperature from 500 to 700°C. As shown in Fig. 3, this is a highly-selective process, depositing only on silicon and not silicon oxide. It is therefore essential that the silicon surface is native oxide free. This is achieved by HF dip-etching and Marangoni drying prior to wafer loading into the epitaxial reactor. As an additional precaution, an in-situ 4 minute thermal pre-bake step is performed at 800°C in hydrogen ambient before PureB deposition.

The silicon dangling bonds on a native oxide free wafer surface are terminated by hydrogen. During PureB deposition, hydrogen is used as the carrier gas. This is beneficial in maintaining the hydrogen passivation of the silicon wafer, thus inhibiting native oxide formation. However, in order for PureB deposition to take place, hydrogen has to first desorb, making sites available for the adsorption of reactant precursors before boron nucleates on the wafer surface. On a clean silicon surface, hydrogen desorbs between 400 and 500°C [7].

The highly-selective nature of PureB deposition poses some difficulties for the process transfer from an epitaxial reactor to a batch furnace system. In an epitaxial reactor, wafer is loaded first into a load-lock, which is pumped down before being transferred into the reactor chamber. Carrier gas passes through a purifier, so that the impurity level is less than 10ppb. However, in a furnace system, a batch of wafers are loaded directly into the process tube. Therefore, water and oxygen levels are not as low as in the epitaxial reactor. As a result, native oxide would form even during the loading in of the wafers, where the furnace temperature can be around 600-800°C. At such condition, the hydrogen passivation on the wafer surface would have desorbed and the water and oxygen levels are sufficient for native oxide growth.

To prevent the formation of native oxide, a likely solution is to load the wafers at a lower temperature, for example at room temperature. However, native oxide may still be formed during the temperature ramp-up of the system to deposition temperature. Therefore, the flow of reactant and carrier gases should be initialized at a temperature before hydrogen passivation desorbs. Eventually, if the impurity levels in the furnace system is a limiting issue and deposition temperature cannot be lowered to prevent native oxide growth, a load-lock could be installed for the furnace system.

![Fig. 2. Schematic of a horizontal batch furnace system [6].](image_url)

![Fig. 3. TEM image of a PureB layer formed directly in a contact window during a 2.5 min exposure to diborane at 700°C. The CVD process selectively deposits on Si and not SiO₂. The inset shows an enlarged view of the edge periphery.](image_url)
Another issue of consideration is the safety issue of using hydrogen as a carrier gas at atmospheric pressure. This is obviously not an ideal processing condition in a furnace system.

A low pressure process with hydrogen as carrier gas would be relatively safer. Figure 4 shows a comparison of current-voltage (I-V) characteristics of p'n diodes fabricated from PureB deposition at 95 torr or atmospheric pressure condition in an epitaxial reactor. Deposition was done at 700°C with 10 minute diborane exposure time using hydrogen carrier gas. The I-V characteristics are similar and ideal for PureB deposited under both 95 torr and atmospheric pressure conditions. Therefore, a low pressure process with hydrogen as carrier gas is a viable alternative.

Eventually, when PureB can be safely deposited in a batch furnace, a further issue of consideration is the uniformity of the deposited PureB layer across a single wafer, as well as wafer-to-wafer along the length of the batch furnace. Gas flow characteristics are very different in a single-wafer epitaxial reactor and in a batch furnace. In an epitaxial reactor, the gas flows parallel to the wafer surface under laminar flow condition and a very uniform PureB can be deposited. This implies that there is limited reactant gas depletion effect across the wafer. In a batch furnace system, it is more complicated to maintain the same flow across the surface of each wafer. Good control of the deposition process would be dependent on whether the process is reaction-limited or mass-transfer limited. The concentration of reactant gas in the furnace is an important process parameter that has to be further tested. The reactant concentration should be sufficiently high to avoid reactant gas depletion effect. At the same time, inefficient utilization of excess reactant gas should be avoided.

**REFERENCES**


