Thinned Wafer Low Temperature Silicon Direct Bonding for Power Device Fabrication

by

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ABSTRACT

The objective of this thesis is to develop a hydrophobic silicon wafer bonding process to fabricate a new type of power device, i.e., a bi-directional insulated gate bipolar transistor (BD-IGBT). The BD-IGBT is a two-gate bi-directional switch that offers higher power capability and efficiency when compared to the standard solution using a combination of IGBTs and diodes. The BD-IGBT also enables a reduction in the die area and total number of packaged parts in a power converter. In order to fabricate BD-IGBTs, it is necessary to bond two thinned IGBT wafers back-to-back with a seamless silicon-to-silicon bonding interface that is electrically transparent to electrons and holes.

There are several major challenges including void formation at the bonding interface, handling of thinned wafers, processing constraints with device wafers, and electrical transparency of the bonding interface to holes and electrons. To prevent void formation: (1) the bonding surface is polished by CMP to atomic scale flatness; (2) contaminants are removed from the wafer surfaces by an ultraviolet clean, piranha clean, and RCA clean; (3) gas diffusion grooves are etched into the silicon surface to provide a path for diffusing hydrogen gas to escape from the bonding interface. Extra care is taken in wafer handling throughout the process to prevent the thinned wafers from breaking. In order to bond wafers with device structures, all processing temperatures remain below 400 °C and the device side of the wafer is passivated with silicon nitride to protect the metallization from being etched by chemicals. An electrically transparent silicon-to-silicon bonding interface is formed by the hydrophobic bonding approach.

This thesis demonstrates seamless thin wafer bonding at temperatures below 400 °C by employing all of the approaches described. The hydrophobic silicon wafer bonding process baseline is developed with a series of prime wafers to determine bonding yield as a function of processing conditions, wafer thickness, bonding surface topography, and device die size. Several inspection techniques are developed to characterize the bonding interface and verify the seamless silicon-to-silicon bonding. The baseline bonding process is expected to enable bonding of functional IGBT device wafers. Hydrophobic wafer bonding allows for the fabrication of double-sided devices without the complexity of double-sided wafer processing; it is critical for the construction of novel devices, particularly for commercializing a revolutionary power converter with BD-IGBTs.