Multiple Wafer Bonding Offers Increased Throughput of High Brightness LEDs

D. Pascual

SUSS MicroTec
228 Suss Drive, Waterbury Center, VT, USA, dpascual@suss.com

ABSTRACT

This report describes an economical tool for the simultaneous bonding of multiple wafer pairs for increasing the manufacturing throughput of high-brightness light emitting diodes (HB LEDs). Up to an 8-fold increase in throughput can be realized with minimal investment since the process is performed with one tool. This article addresses the advantages and technical limitations of this method that should be considered upon implementation. The two most common metal-to-metal wafer bonding techniques for HB LEDs are reviewed. A detailed description of the bonding apparatus and its operation will be given. We also discuss process considerations that affect bond quality and uniformity.

Keywords: wafer bonding, high-brightness light emitting diodes, eutectic bond, gold-gold bond

1 INTRODUCTION

The need for efficient, high intensity lamps for common lighting applications such as traffic signals, automotive lighting, and backlit displays has driven the demand for high-brightness light emitting diodes (HB-LEDs). However, widespread acceptance of HB-LEDs has mostly been limited by its relatively expensive cost per lumens [1]. This obstacle has challenged manufactures to produce LEDs that extract the maximum amount of light while reducing the cost of manufacturing in order to gain market share.

In a typical LED active region, spontaneous emission scatters photons in all directions. If the substrate material has a smaller bandgap than the active region, approximately half of the light is absorbed there, which significantly reduces device performance. To overcome this problem, manufacturers such as Osram, Sanken, Oriol, VPEC and UEC have developed metal bonding techniques that involve the transfer of an epitaxial layer to a reflective substrate [2], which also provides mechanical support, electrical contact, and thermal management. The metal layer reflects light back through the active region and maximizes light extraction. However, material properties have limited wafer sizes to the 2 and 3 inch diameter range, which limits the number of devices that can be produced with each wafer bonding cycle when processing one pair at a time. In order to meet the demands of LED manufactures to increase throughput while reducing costs, we have developed a wafer bonding tool that can process multiple wafer pairs in a single run. The concept behind the tool is simply to perform the same type of bond but scaling it up with multiple pairs in parallel. To better understand the utility as well as the limitations of this method, let us first describe the metal bonding techniques used for HB-LED's.

2 METAL BONDING TECHNIQUES

The two most common metal-to-metal wafer-bonding techniques used for HB-LED's are Au-Au thermocompression (TC) bonding and AuSn eutectic bonding. Au-Au TC bonding requires that a thin layer of gold be deposited (typically 1 – 5 µm thick) on each of the mating wafers along with the appropriate barrier layers. Any surface contaminants (e.g. organics) can impede the solid state diffusion mechanism necessary for TC bonding. The use of a standard cleaning step such and UV ozone treatment or wet chemistry prior to bonding is typically utilized to promote strong bonds. Once the gold surfaces are brought into contact, an elevated temperature is needed to soften the metal enough so that it is easily deformed under moderate to high pressures. A temperature range of 300 – 400 °C and pressure ranges of 1-7 MPa for times ranging from 10 minutes to several hours have been reported. It has been observed that lower temperatures require longer times and/or higher pressures in order to obtain a homogeneous bond interface. In contrast, insufficient bonding times and pressures result in highly localized bonded regions. TC bonding may be performed using other soft metals such as Cu, however, Au is the metal of choice due to its resistance to oxidation.

Metal bonding may also be performed using a AuSn (80/20) eutectic alloy, which has a melting point of 278°C (Figure 1). In contrast to TC bonding, eutectic bonding occurs through solid/liquid diffusion as intermetallic alloys are formed. Typically, a gold layer is deposited on one of the mating wafers while the other receives a thin layer of the AuSn up to 5 µm thick (appropriate diffusion barriers may be needed). The Sn component exposes the alloy to the risk of oxidation during elevated temperatures. For this reason, it is crucial to supply an inert environment that is depleted of oxygen and possibly contain some sort of reducing agent such as hydrogen. Forming gas (95% N_2, 5% H_2) is typically chosen. Once the wafers make contact in an appropriate environment, they are subjected to a temperature slightly above the melting point for a short period of time (about 2 minutes) and then cooled to solidify the bond interface before releasing. During the bond, only a slight amount of pressure is needed to ensure that there is intimate contact between the wafers.

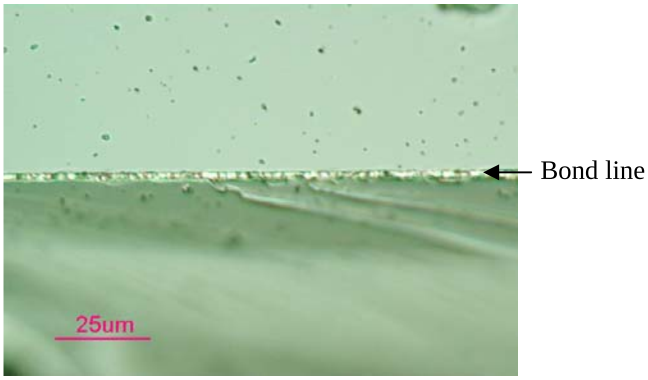

Figure 1: Cross section of bonded wafer pair showing AuSn bond line.

3 MULTIPLE WAFER BONDING TOOL

The multiple wafer bonding tool is based on an 8-inch diameter platform. The two main components are the bonding chamber and a specialized fixture that can be removed from the chamber. The chamber contains a top and bottom heater as well as mechanisms for the application of force onto the fixture. During bonding, the chamber is completely sealed to allow for pressure regulation and process gas confinement. The fixture holds the wafer pairs during loading and is positioned between the top and bottom heaters during bonding. The fixture itself is composed of a base plate with a detachable top plate; both made from silicon carbide (Figure 2). A thermocouple is incorporated into the base plate for more accurate temperature control and is connected to the bond chamber through spring loaded contact pins. A compliant sheet, such as a graphite foil, can be attached underneath the upper plate to distribute the bonding force uniformly over the wafer surfaces.

In a typical bonding cycle, the base plate of the fixture is manually loaded with up to 8 pairs of wafers – each 2 inches in diameter. Since wafer alignment is performed manually, only a rough flat-to-flat alignment is possible. (An automatic system is currently under development.) Outlines on the base plate surface help to position the wafer pairs evenly. Once all the wafer pairs are in place, the top plate, along with a compliant sheet, is lowered on top of the wafer pairs to maintain their position during transportation of the fixture. The fixture is inserted in between the top and bottom heaters from the side of the bonding chamber using a loading stage. The bottom heater moves up to overtake the fixture, which allows the loading stage to be removed from the chamber. With the loading stage out of the way, the chamber opening can be closed so that the process gas and pressure can be controlled. Heat and force are applied through the fixture to create the bond. Afterwards, the fixture along with the wafers are cooled to the desired temperature and removed with the loading stage. The operator then unclamps the top plate, removes the bonded wafers, and repeats the cycle.

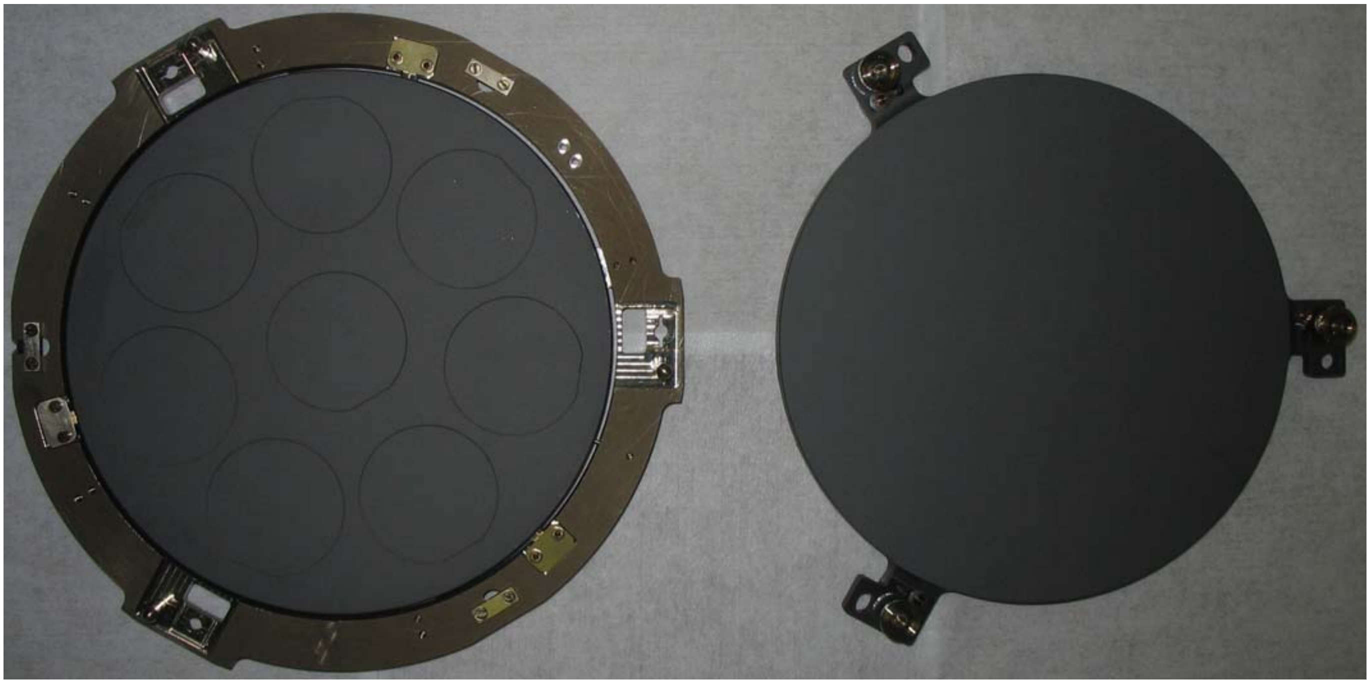

Figure 2: Left – Fixture base plate with outlines for 8 two-inch wafer pairs. Right – Fixture top plate

4 PROCESS CONSIDERATIONS

Wafer-to-wafer alignment is an important consideration for this multiple wafer bonding process. In most HB-LED applications, wafers are coated with a blanket layer of metal, which makes high-accuracy alignment unnecessary. The current design of our tool utilizes a manual flat-to-flat alignment, which is sufficient for blanket coated wafers. We are currently designing a system for more precise alignment.

Bonding force is essential for bringing the wafers into intimate contact especially for the case of Au-Au thermocompression, which requires high force and heat for sufficient diffusion across the metal interface. Several factors can impede intimate contact including wafer bow or warpage as well as irregularities in the deposited metal layer. The upper limit for bonding force on our tool is currently 20 kN. When estimating the amount of force necessary for this process, one must also include the amount of pressure necessary to flatten curved wafers. In most cases the optimal bonding force is determined experimentally.

Increasing the number of wafer pairs to be bonded in parallel (i.e. side-by-side) divides the applied force over a larger area and decreases the actual pressure experienced by each wafer pair. Another method is currently being investigated where wafers are stacked vertically, one on top of the other. It has been speculated, however, that such a configuration may cause a large temperature gradient vertically through the wafer stack.

In most cases, a compliant sheet of graphite foil is employed for the uniform distribution of force across the wafer pairs. Because the wafer pairs are spread out across a large area, a high degree of co-planarity between the top and bottom heaters (< 20 µm across the 200 mm surface) as well as a 3 µm flatness of the silicon carbide plates has been specified for this tool. The additional graphite layer provides a certain degree of compliancy for wedged wafers and differences in stack thickness between wafer stacks. Therefore thickness irregularities should be minimized for the best possible pressure uniformity.

5 SUMMARY

A multiple wafer bonding tool has been described for increasing the manufacturing throughput of HB-LEDs by up to 8 times with minimal equipment costs. Wafer pairs are processed in parallel in a specialized fixture designed for clamping wafers in place during transport. Various process considerations have been described that should be taken into account upon implementation of this tool.

REFERENCES

[1] D. Huo et. al., *Compound Semiconductor*, Dec. 2003

[2] S. Illek et. al., *Compound Semiconductor*, Jan. 2002