WAFFER BONDING TECHNOLOGY FOR HB-LED MANUFACTURING

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Abstract
Wafer bonding is the enabling technology for active layer transfer of AlInGaP and InGaN vertical LEDs. In this case superior thermal and electrical properties of the LEDs ensure high power operation, which is needed for future applications such as general lighting. While thermo-compression bonding is often applied for LEDs grown on GaAs, eutectic and solder bonding dominates for InGaN LEDs, generally grown on sapphire substrates. The selection of the substrate, bonding process and material system as well as appropriate adhesion layers and diffusion barriers is essential for a high yield layer transfer bonding process. In this contribution we will focus on fabrication and bonding technology for active layer transfer of red AlInGaP and blue InGaN LEDs.

High brightness LEDs (HB-LEDs) are an up-and-coming solution for general lighting which is expected to be the third big cycle of LED market growth. However, the cost per lumen is still about a factor of ten too high to be competitive in the general lighting market. Several parameters and processes still have to be optimized in order to lower HB-LED manufacturing cost. One of the main influencing factors for cost is the total lumen output that can be extracted from one LED die, hence reducing the amount of dies needed for a luminaire. One could think, increasing the current is increasing the lumen output. Yet the droop effect, meaning a cutback of the internal quantum efficiency with increased current density, introduces different issues. In other words, more current generates more light, for the price of reduced efficiency and much increased waste heat. Getting rid of the heat is essential to guarantee high reliability and hence lifetime.

Another way to increase the luminous flux per package is the use of larger LED die sizes. However, having a homogenous injection and distribution of the current throughout the whole chip are, demands further chip design efforts. Mainly for these two reasons, the so called vertical thin film LEDs (VLEDs) have been developed.
The overall process flow for manufacturing of a VLED is depicted in Fig. 1. After growth of the LED layers, wafer bonding for layer transfer is the central fabrication step for a high overall yield. Following the bonding step, the growth substrate is removed and the surface is patterned for optimum light extraction. Generally, the structurization of the LED, done by photolithography and reactive etching processes, can be conducted before or after the bonding process. Major influence for this decision is the following process step to remove the growth substrate.

For InGaN-based blue LEDs, laser lift off (LLO) is commonly used to remove the sapphire substrate. Therefore, an excimer laser is coupled into the sapphire growth substrate. While sapphire is non-absorbing under such wavelengths, all the energy is absorbed in the first tens of nanometers of n-doped GaN, leading to decomposition into gallium and nitrogen. Due to the stepping nature of this laser process, strain is introduced, which may lead to GaN layer cracking and hence destruction of whole LED regions. Structurization of the LED wafer and confinement of the laser beam to single or multiple of the LED die size is effective to reduce cracking and increase the yield of the LLO process. For AlInGaP LEDs on the other hand the GaAs growth substrate is generally removed by grinding and chemical etching, enabling full-area wafer bonding.

Wafer bonding is one of the essential processing steps in order to achieve a high process yield in this layer transfer process. For layer transfer of VLEDs, two metal bonding processes can be used: the first process is eutectic, solder or diffusion bonding and the second is metal thermo-compression bonding. The choice of the process for metal bonding is determined by the physical properties of carrier and growth substrate, e.g. thermal expansion coefficient and maximum temperature stress to inhibit interdiffusion. On the other hand, the surface quality is a major contributor to the bonding result. As an example, AlInGaP red LEDs are grown on GaAs where the lattice matching is good and a low defect density results in a highly flat surface after growth. Here Au-Au thermocompression bonding is frequently used, where high quality surfaces are required for a direct contact and high bonding yield. On the contrary, InGaN blue LEDs are generally grown on sapphire (also silicon is emerging to mass production recently) with a high lattice mismatch and hence lot of defects and a high roughness. Here, eutectic or transient liquid phase bonding is regularly used, where the interface melts up during bonding and planarizes such inhomogeneities (a scanning microscopy image for Au:Sn eutectic bonding can be seen in Fig. 2).

After the metal bonding process has been selected the thickness of and deposition technique for the bonding metals has to be determined. Since several of the bonding metals have a high solubility in semiconductors, barrier layers as well as adhesion layers for wetting are necessary. For this reason, typically multilayers of Pt, Al or Au are used in the metal bonding stack.

Wafer bonding is the enabling technology for active layer transfer of AlInGaP and InGaN vertical LEDs. In this case superior thermal and electrical properties of the LEDs ensure high power operation, which is needed for future applications such as general lighting. While thermocompression bonding is often applied for LEDs grown on GaAs, eutectic and solder bonding dominates for InGaN LEDs grown on sapphire substrates. The selection of the substrate, bonding process and material system as well as appropriate adhesion layers and diffusion barriers is essential for a high yield bonding process.

References