Image sensor packaging gets thin

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Solid state image sensors require protection from the ambient atmosphere. First-generation imagers were housed in standard semiconductor packages with glass lids. These were hermetic and delivered exceptional protection for the die, but were also bulky and expensive to manufacture. The introduction of wafer-level packaging, where the costs of the fabrication processes are shared among the good die on a wafer, resulted in a substantial reduction in cost and nearly an order of magnitude reduction in package thickness. Innovation in materials, assembly processes and semiconductor technology has enabled these trends to continue. Modern solid state imagers are commodity items, having a total package thickness of just a few hundred microns, yet they will pass automotive reliability specifications.

Solid State Imagers
Solid state imagers are fairly conventional semiconductor die, built on silicon wafers, where each die has a light-sensitive area. Image sensor die require protection from the ambient atmosphere in order to ensure their longevity. The principal failure mechanisms are corrosion, mechanical damage and obscuration.

Corrosion
Air, or more accurately the moisture contained in normal atmospheric air, is highly corrosive towards semiconductor die. Functional semiconductors are complex, multi-layer assemblies, where the outer most layers are very fine bus bars of aluminium. Aluminium possesses a very high electrode potential so that rapid corrosion ensues when placed in contact with other metals and in the presence of moisture to complete a galvanic circuit. The external interconnects to the semiconductor are, by necessity of function, made of metals other than aluminium, so it is essential to keep moisture away from image sensor die at all times.

Mechanical damage
The light-sensitive area of an imager is covered by an array of minute, hemispherical lenses. These lenses serve to focus the light that falls on each picture element (pixel) in the imaging area onto the light-sensitive regions of the semiconductor. The remaining area of the imager is not sensitive to light, because there are some electronics and wiring lines associated with each pixel. These micro-lenses are made of soft polymers and are extremely delicate. Any physical contact would result in catastrophic damage to them.

Obscuration
On a modern solid state imager, individual pixels will typically measure 3μm on a side or smaller. This is tiny in comparison with dust particles in normal ambient air. The micro lenses that sit over each pixel are not only soft and easily damaged, but are also slightly tacky, due to a combination of
electrostatic charging and their surface chemistry. This means it is nearly impossible to remove a dust particle once it lands on a pixel. Clearly, if the size of the dust particle approaches that of the pixel, it will block the incident light, resulting in a black pixel in the image. The human eye is very sensitive to static defects in an image, and even a single dead pixel is an annoyance.

One effective solution to all the above failure mechanisms is to house each imager in a package. The package is sealed to prevent moisture from reaching the die, while a glass lid allows the light passage to the sensitive area, but protects against mechanical damage and particle contamination.

Next: Ceramic Image Sensor Packaging

Ceramic Image Sensor Packaging

The first generation of solid state image sensors were housed in ceramic packages (see Figure 1). These are identical to the packages used for conventional semiconductors, except that glass or quartz is used in place of the traditional metal or ceramic lid. The walls and base of the package will be approximately 1mm thick and the lid about 500μm thick. Ceramic packages are quite large because the die well has to be large enough to accommodate assembly and die size tolerances. In addition there is a shelf of lands surrounding the die, which increases the X/Y dimensions of the package. Fine wires are used to make connection between these lands and the bond pads on the die. Electrical connection to the package will be achieved by leads that emerge from the side or wrap around to the underside, or by an array of lands or solder spheres on the rear face. Including these interconnects the total package height is about 5mm.
Figure 1: Ceramic enclosure for a solid state image sensor. The die is attached to the package base and electrical connection is made between the die and terminations inside the package by wire bonds. The package is sealed by a glass lid. Each pixel on the die is covered by a hemispherical micro lens.

From a technical standpoint, these types of packages are ideal and, indeed, many high-performance imagers (e.g. 20+ Mega Pixel) still utilize this form of enclosure. The combination of a single-piece ceramic base together with a glass lid attached by a metallic joining process means the package is totally hermetic. Thus, a particular atmosphere, such as dry nitrogen, can be sealed inside the package and will be sustained for decades. The imager is well protected against mechanical damage, and any dust particles that land on the glass lid can be easily removed, if necessary by wiping or washing. Also, because the glass lid is spaced a considerable distance from the micro lenses, the size of dust particle necessary to cause a defect in the image is quite large. Even then, the blemish appears as an area of lower intensity, with a diffused boundary, and so is far less perceptible to the human eye.

The principal drawbacks of this style of package are cost and size. Even in high volume, the unit price of ceramic packages is usually expressed in dollars. Also, each packaged imager must be assembled as a discrete item so the process costs are relatively high. For application in portable electronics products, like cell phones, a ceramic package is simply too large, too thick and too expensive to be acceptable.

Next: Wafer-Level Packaging

Wafer-Level Packaging

Wafer-level packaging of semiconductors is an economically attractive proposition. The basis of the approach is to encapsulate all die on a wafer simultaneously, while they are still in wafer form, and then free the individually packaged parts. This approach has the singular advantage that the process costs are shared among the good die on the wafer. With typically between 750 and 1,500 die on a 200mm diameter image sensor wafer, this results in an order of magnitude decrease in the package
cost per die compared with discrete ceramic packages.

Although wafer-level packaging appears simple, it is only recently that the materials, tools and expertise required to make manufacture in volume viable have been achieved. The first generation of wafer-level packages for image sensors involves bonding a glass wafer onto the front face of the image sensor and a second glass wafer onto the rear face (see Figure 2). The adhesive for the front face joint is specially selected to be optically transparent. The cross-sectional symmetry of the package ensures all the forces are balanced. The electrical interface for the die is an array of solder spheres, also known as a ball grid array (BGA), on the rear face of the package. Various proprietary schemes are used for forming the connections between the BGA and the semiconductor die. The total package thickness, including the solder spheres, is approximately 900μm.

![Figure 2: Image sensor protected by a package formed at the wafer level. Glass plates are attached to the front and rear face of the die by an optically transparent adhesive. The bond pads on the die are connected through the structure to a ball grid array interface of solder spheres on the underside of the package.](image)

The package shown in Figure 2 is only suitable for low-resolution imagers, such as CIF devices,
which do not use micro lenses on top of each pixel. This is because the optical adhesive has a higher refractive index than air and, consequently, impedes correct operation of the micro lenses. This problem was solved by spacing the front glass from the die by a few tens of microns, so there is a small air gap above the micro lenses. The front glass is therefore only attached to the die by a picture frame of adhesive that surrounds the light-sensitive area. The reduction in mechanical coupling between the die and the front face glass permits the glass on the rear of the die to be roughly halved in thickness, reducing the total package height to around 700μm.

The dimensions for a wafer-level package, in plan, are dictated by the size of the die. As the completed packages are diced directly from the wafer, the chip and package dimensions are one and the same. This attribute is unique among semiconductor packaging solutions. Hence, wafer-level packages are sometimes also referred to as "chip-sized packages".

Next: Third-Generation Wafer-Level Packages

Third-generation wafer-level packages

The current fashion in portable electronic devices is for extreme thinness. At the same time, other industries are exploiting image sensors in large numbers. One example is the automotive industry, where various driver aids are being integrated with the central information console that also displays vehicle diagnostics, entertainment system status and navigation information. Image sensors for automotive applications are required to hold reliability specifications that are arduous by comparison with those demanded for cell phones. This is not surprising given the average life of a cell phone is months, owing to regular replacement by a newer or better model not technical malfunction, compared with years for a typical domestic car. Furthermore, a cell phone will mostly be subject to a benign environment, whereas an image sensor on a vehicle will be exposed to extreme climates, including periods of total immersion in water.

Although image sensors for automotive applications are not constrained by size and weight, their integration in these systems is driven by cost. And so, though image sensors protected by ceramic packages are suitable for automotive applications, a more cost-effective solution is desirable. Third-generation wafer-level packages for image sensors have been developed to meet the twin objectives of simultaneously reducing the package thickness further and meeting strict automotive reliability specifications.

The key differentiator of third-generation wafer-level packages for solid state imagers is that the glass plate on the rear face of the die has been replaced by a specially formulated polymer. A slight change to the package structure and process flow enables this polymer to join to the front face glass, thereby providing a robust seal around the entire periphery of the device (see Figure 3). This makes it possible for the package to pass automotive environmental tests. Eliminating the second glass wafer from the package removes a relatively expensive component, so third-generation wafer-level packages are appreciably cheaper than first- and second-generation solutions. The polymer layer is an order of magnitude thinner than the glass layer it replaces, making the device suitable for the latest and thinnest portable electronics devices. At the same time, progress in semiconductor technology has resulted in a steady reduction in the thickness to which the silicon die can be thinned without compromising the performance of the imager. Whereas first-generation imagers required the silicon to be about 500μm thick, this limit has now been decreased to close to 100μm for current designs. The net result is that third generation image sensor packages can have a total thickness below 500μm.
Figure 3: Third generation wafer level package for a solid state image sensor. A spacer wall (depicted in green) provides a cavity between the micro lenses and the cover glass. A thin polymer layer provides a complete seal over the rear face of the die and the package side wall to the cover glass. The bond pads on the die are connected through the structure to a ball grid array on the underside of the package.

Conclusions
Solid state image sensors must be packaged to protect against corrosion, mechanical damage and obscuration by dust particles. Solid state image sensors were initially housed in totally hermetic, discrete, packages but these have been largely replaced by wafer-level packages. The wafer-level packages have undergone progressive evolution in response to market demands for thinner, cheaper and more reliable packaged imagers. The current generation technology provides a low-cost, chip-size solution with a total thickness of less than 500μm that will also pass stringent automotive reliability standards.

About the authors
Giles Humpston, Ph.D., serves as Director, Research and Development of Tessera, Inc., where he currently focuses on packaging of solid state camera modules and product miniaturization through wafer-level technologies. He has worked extensively in the field of semiconductor packaging, initially for military applications and more recently for high-volume consumer products. Dr. Humpston is a cited inventor on more than 75 patents and has co-authored several text books on metallic joining processes. He has a Ph.D. in alloy phase equilibria and is a metallurgist by profession. He can be reached at ghumpston@tessera.com.

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