Silicon interposers that fit the “2.5D” definition will, within a year or two, move into volume production and provide high performance in a small, relatively inexpensive package having multiple functions. Right now, though, the 2.5D interposers are going through the rigors of design and development— which explains why so many wind up at Sonoscan for advanced acoustic micro imaging.

Typically 2.5D configurations have one or more flip chips on top, connected by microbumps to the interposer itself. Through-silicon vias in the interposer serve as a complex redistribution layer, and are connected to the substrate below by larger solder bumps. The microbumps are typically 20 to 30μm in diameter, while the solder bumps are typically 100μm in diameter.

As one would expect during a period of active development, there are numerous variations among the many 2.5D samples that have come to Sonoscan. The makers of the packages are interested in seeing acoustic images that reveal the integrity and bonding of the tiny microbumps and the larger solder bumps, as well as the integrity of the two layers of underfill. Acoustic micro imaging is the best choice for quick, non-destructive evaluation because it can detect whether materials are bonded or not. X-ray can detect materials, but not bonding or the lack of bonding. Acoustic micro imaging can also bypass physical sectioning, which might well cut through the configuration at the wrong location, and which has the potential to produce artifacts that might be mistaken for defects.

The frequencies employed in acoustic micro imaging systems fall into two arbitrarily defined groups: Very High Frequency (from 5 MHz to 75 MHz), and Ultra High Frequency (from 100 MHz to 400 MHz). Silicon interposers require high resolution and therefore are typically imaged with UHF transducers; the same is true of less expensive glass interposers. Understandably, all 2.5D samples are currently highly confidential, so no acoustic images accompany the text of this article.

All of the silicon interposer samples that have been sent to Sonoscan so far have been underfilled between the flip chip (or chips) and the interposer, and between the interposer and the substrate, as shown in FIGURE 1, which is not to scale. None of the samples was overmolded. There is considerable variation in the thickness of the chips. The flip chip may be as thick as 500μm, but is usually somewhat less. The silicon interposer is thinner, sometimes as thin as the 100μm solder bumps on which it rests. The top member of the assembly may be a single large flip chip, or multiple side-by-side smaller flip chips, which sometimes appear optically to be a single flip chip. Overall, imaging a 2.5D sample is somewhat similar to imaging a flip chip, but the number of internal interfaces is larger, making the imaging process somewhat more challenging.

All of the silicon interposer samples submitted have been imaged successfully. The firms submitting the samples want to see acoustic images of the 20μm
and 100 µm solder bumps to determine that they are present, intact and well bonded at their top and bottom surfaces. Even if its vertical extent is as little as 0.01 µm, the gap that exists where a bump is not bonded reflects virtually all of the ultrasound. It thus creates a bright feature in the acoustic image or, in some cases, may simply appear as a missing bump in the pattern.

Firms submitting 2.5D samples are also interested in the presence of voids or other anomalies in the underfill material. Voids have been imaged in the underfill beneath the flip chip and in the underfill beneath the silicon interposer. Voids are significant, especially when adjacent to a solder bump, because the local absence of underfill can permit leaded solder in particular to migrate into the void until the bump deforms and loses its electrical connection. A second mechanism is the fracturing of a bump that is adjacent to a void; this type of failure is far more common in the lead-free solder typically used in silicon interposer assemblies.

Also of interest are cold solder joints and bumps that are delaminated from the underbump metallization. On occasion other types of defects may be found. To date, aggregations of filler particles within the underfill have not been observed to be an issue.

The acoustic frequency used to image the flip chip bumps and interface bumps can be limited by structural features in the assembly. For example, some flip chips have a low-k dielectric layer made of any of several porous materials that attenuate ultrasound. There may also be a polyimide (PI) layer that coats the active surface of the flip chip. Since it is a polymer, the PI layer could also cause signal loss at high frequencies.

To date all silicon interposer samples have been imaged by standard Sonoscan transducers, but it is already evident that there may be advantages to imaging silicon interposers with customized transducers fine-tuned to the silicon interposers’ geometries and materials.

In some samples better data and images about each solder bump layer can be used by employing software that allows the operator to divide the depth of interest into a number of individually gated depths, for each of which an acoustic image will be made during a single transducer scan. The maximum number of gates is 200. In silicon interposer samples the two depths of interest are the two underfill layers, the solder interconnects in these layers, and the interfaces with layers above and below the underfill. These two depths are respectively about 25 µm microns and about 100 µm in vertical extent. Any desired number of gates can be set to image one of these depths. Each gate generates a single acoustic image, so a sequence of images moving downward through a layer creates what amounts to a slide show. If there is an anomaly in the solder bumps or the underfill, these images may provide detail.

The gates are normally set up to be adjacent to each other, but they can also be overlapped. Overlapping the gates increases the number of images and can provide even more information. The value of the method is limited, though, if the flip chip is warped. Part of each image will represent depths outside of the desired gate, and the images will therefore appear distorted.

The imaging of details in the interposer-to-substrate bumps can be challenging because of the number of interfaces ultrasound must travel through. Often these details can be enhanced by switching from the normal time domain imaging to a Frequency Domain Imaging (FDI) method. FDI decomposes the return echoes from a given depth range into individual frequencies. The depth range is often the vertical extent of the solder balls and underfill. From the decomposed echoes an acoustic image is made for each frequency; thus in one scan a single transducer might create 20 to 30 images, all from the same depth range, and all with the same transducer focus.

Examining these images, the microscope operator will notice significant differences in the imaging of features from one frequency to the next. A small or elusive anomaly such as bump damage or a void that would escape notice in a time domain image is very likely to be visible in one or more of the FDI images.