What's Driving Substrate Shortages?

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Unexpected demand, global supply chain uncertainty, accidents, and weather-related events have resulted in semiconductor shortages. All types of substrates are in short supply; including substrates for chip scale packages (CSPs) and flip chip ball grid arrays (FC-BGAs). Despite some capacity expansion over the next few years, and new plants planned to come online in 2024-25, the situation is not expected to improve for at least two to three years. Some companies are considering substitutes that do not use substrates, including fan-out wafer level packages (FO-WLPs). Layer count reduction in substrate designs with the adoption of RDL is also under consideration.

What's Driving Demand for FC-BGAs?

FC-BGA substrates fabricated with build-up materials are required to support the fine pitch bumped die used for applications including CPUs for servers, laptops, and desktops, AI accelerators, ASICs found in telecommunications, media chips such as HDTV, DSPs, and FPGAs.

Unlike many segments of the industry, the shortage of FC-BGAs is not driven by the pandemic. While there is increased demand for servers, laptops, and desktops demand for additional substrate manufacturing capacity is primarily driven by the larger body sizes and increased layer counts in some segments. ASICs have a range of body sizes, and a common substrate uses a 4-2-4 build-up construction. While many applications use a 2-2-2 build-up constructions, others use much higher larger counts and body sizes. Apple's M1 uses a 3-2-3 build-up construction (see Figure 1).

Increased body sizes and layer counts for server CPUs are a major contributor to higher demand for substrate capacity. High-end server CPUs are expected to use body sizes up to 100mm x 100mm with 10 build-up layers on each side of the core. At the high end of the spectrum, high-end network switch packages range between 70 mm to 90 mm on a side. OSATs report they expect to see requirements for 100mm x 100mm substrates by 2023. Larger body sizes are being considered. The minimum layer count is six or seven build-up layers per side, with a few eight- and nine-build-up layer designs on the horizon. While the volumes are low in terms of units, the panel requirements are large because the substrates are large and complex, impacting layout on the panel as well as panel yield. Co-packaged optics is expected to use even larger body sizes of 110 mm x 110 mm.

What about silicon interposers? Don't many applications use them for the package? Yes, silicon interposers used for AI accelerators, high-performance FPGA applications, and high-end network switches, but they are attached to a laminate build-up substrate to complete the package. The silicon interposer is attached to the laminate substrate with solder balls, typically with a pitch of 130 µm. A typical AI accelerator has a 55mm x 55mm body size. As the interposers increase in size larger build-up substrates will be required. TSMC has proposed extremely large 2,500 mm^2 silicon interposers that will require an even larger substrate[1] (see Figure 2). Samsung's silicon interposer with a 85mm x 85mm build-up substrate has been demonstrated.

Companies including ASE, Amkor, SPIL, and TSMC have introduced fan-out on substrate options. FO on substrate options also uses a laminate build-up substrate to form the package. The use of an RDL interposer can reduce the number of build-up layers in the supporting laminate substrate, but a laminate substrate is still required. It helps that the finer pitch to support the high-density bump can be handled by the RDL instead of the build-up film. However, FO substrates can also be very large. TSMC has demonstrated a 51mm x 42mm area with five redistribution layers (RDLs) on a 110mm x 110mm substrate.[2]

Unit volume growth for FC-BGA substrates using build-up material is projected to increase a little over three percent from 2020 to 2025. As layer counts and body size increase, the demand for build-up manufacturing capacity also increases. This drives demand for an increased number of substrate panels to be processed. The largest body-size packages today include server CPUs, AI accelerators, and high-end network switches. By 2025 these packages will account for 48 percent of the demand for manufacturing capacity.

Build-up Substrate Production: It's Complicated

Build-up substrates are manufactured using a sequential process. A 2-2-2 substrate requires two passes through the production line, compared to one pass for a 1-2-1 substrate, so the required substrate manufacturing capacity increases with each additional build-up layer. This drives the demand for increased FC-BGA capacity. Furthermore, with each additional build-up layer there is a yield decrease. With larger body sizes Yields are low for larger size substrates with higher layer counts. Low yields, coupled with the layout of the large body size on the panel, it may be possible to only have one or two parts per panel.

Capacity Expansion for FC-BGAs

To meet the growing demand, several companies have announced plans to add FC-BGA capacity. Companies including AT&S, Kinsus, Kyocera, Nan Ya PCB, Toppan, Samsung Microelectronics Company, Ltd. (SEMCO), Shinko Electric, Toppan, and Unimicron have all announced capacity expansions from this year through 2025. Domestic Chinese suppliers such as Shennan Circuit (SCC) and PCB maker ZDT (Avery) are also planning to enter the FC-BGA substrate market. However, the growth in larger body size and higher layer counts threatens to continue to outpace the capacity expansions. Figure 3 shows the gap in substrate demand vs. capacity measure in area.

Equipment and Materials for Substrate Production

One of the major challenges in capacity expansion is the long lead times for some key production equipment, which has stretched to almost two years. This means that planned capacity with construction starting today will not be ready for two years and then the substrate sill needs to be qualified.

There are concerns about the materials for substrate production such as materials to produce the core and the build-up material. There are two many suppliers of build-up material: Ajinomoto and Sekisui Chemical. Ajinomoto has a major share of the market and promises to keep up its capacity expansion to meet demand. Core material suppliers are also expected to try to maintain sufficient capacity to meet demand.

Potential Solutions: Improved Yield and Alternatives

Several substrate suppliers will focus on yield improvement as a way to increase production. However, the larger body size and increased layer counts make it challenges to achieve major improvements and even with improvements yield improvements build-up substrates will remain in short supply.

A number of companies have proposed alternatives to today's build-up substrates or alternatives that will require the use of fewer build-up layers in the organic substrate or provide a lower cost alternative to build-up substrates with high layer counts.

3D stacking of devices has the potential to reduce the area required for the substrate, and companies are expected to use this option in the future. However stacking die with microbumps or hybrid bonding requires good thermal solutions and careful design.

Research organizations such as Georgia Institute of Technology (Georgia Tech) and Fraunhofer Institute, as well as companies including AGC, Corning, DaiNippon Printing, Mosaic Microsystems, Samtec, SCHOTT, Toppan, and Unimicron have conducted extensive research on the use of glass as a substrate or as a core material. While progress continues and solutions such as RF applications show promise, glass will not be able to provide a quick solution to the laminate substrate shortage.

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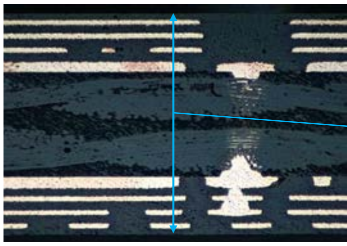
[1] P. Huang et al., "Wafer Level System Integration of the Fifth Generation CoWoS®-S with High Performance Si Interposer at 2500mm^2," *Virtual Electronic Components and Technology Conference*, June 1 – July 4, 2021, pp. 101-104.
[2] Y. Chiang et al., "InFO_oS (Integrated Fan-Out on Substrate) Technology for Advanced Chiplet Integration," *Virtual Electronic Components and Technology Conference*, June 1 - July 4, 2021, pp. 130-135.

FC-BGA Build-up Substrate



- Eight-layer (3-2-3) build-up substrate
- 3 build-up layers sequentially fabricated on each side of core

Source: TechSearch International, Inc..

Figure 1

Silicon Interposer

Source: TSMC.

2,500mm² Si interposer, 8 HBMs, 2 Logic die 600mm², in 75mm x 75mm package Silicon interposer mounted on laminated build-up substrate

Figure 2

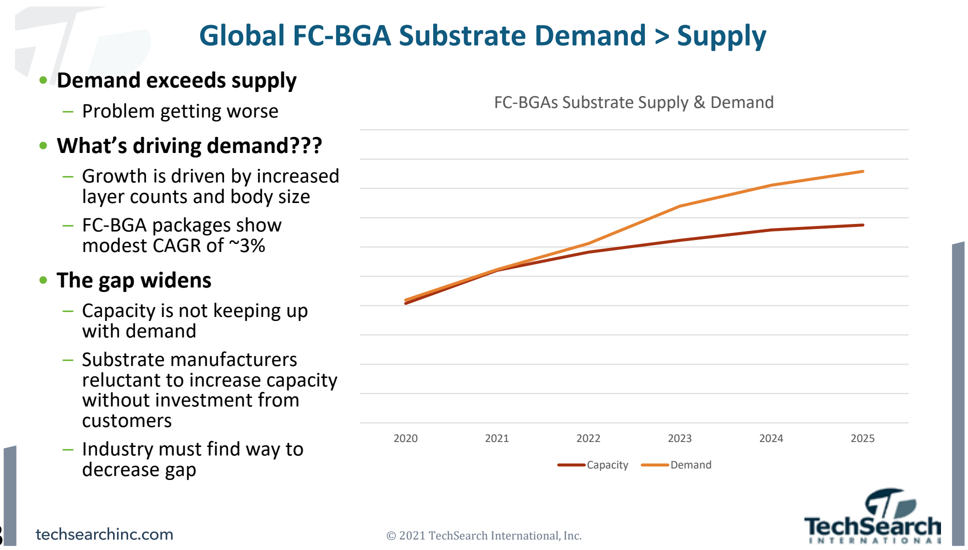

Global FC-BGA Substrate Demand > Supply
Demand exceeds supply
Problem getting worse
What's driving demand???
Growth is driven by increased layer counts and body size
FC-BGA packages show modest CAGR of ~3%
The gap widens
Capacity is not keeping up with demand
Substrate manufacturers reluctant to increase capacity without investment from customers
Industry must find way to decrease gap
FC-BGAs Substrate Supply & Demand
2020
2021
2022
2023
2024
2025
Capacity
Demand
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Figure 3