High Accuracy and High Throughput Solutions for Flip Chip on Flex (FCOF) Assembly

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Abstract
As the drive toward higher performance data storage devices continues, flex assemblies used in these products have become more complex. An example is using flip chip technology to attach the pre-amplifier IC to the flex cable, referred to as Flip Chip on Flex or FCOF. The ever-increasing requirement for performance has translated into high demand for such assemblies, thereby fueling the need for a high accuracy and high throughput die placement solution. The major technology and market drivers for FCOF will be reviewed in this paper, as well as the equipment-related solutions to issues that are specific to FCOF assembly. Imaging of flex substrates, for example, presents challenges due to the copper/polyimide materials used in the manufacture of the flex circuit. Solutions to such challenges will be presented. Also, the requirements to place passive components and connectors, in addition to the active pre-amplifier device, will be reviewed and complete assembly solutions that meet both the accuracy and throughput requirements will be presented.

Introduction
The need for more computer data storage capacity appears to be endless. Over the last decade, storage density has increased by an order of magnitude. And, undeniably, the prevailing media for storage remains magnetic. Annual growth of more than 100% in areal density, a measure of storage capacity per unit area, has been recorded. Areal densities in the order of 100 Gbit/square inch are projected by 2005 (References 1,2). In parallel, the price of storage has been steadily decreasing by 40% every year as production expands. Even taking into account the continuous increase in magnetic disk capacity, the annual production of magnetic disk drives has gone from about 145M units in 1998, to 170M in 2000, and is projected to reach 250M in 2003 (Reference 2). In addition to the growing technological complexity of read/write heads and media, the disk drive assembly also includes leading edge packaging technology, such as high-density board assembly and advanced flex cable assembly. The challenges associated with such flex assemblies are addressed in this paper.

A typical hard disk drive assembly consists of the drive, a circuit board controlling the heads, spindles, and actuators, and an interconnecting flex cable. And, one of the electronic devices critical to the reliable performance of the drive is the preamplifier semiconductor chip. This device receives data from the read/write head and then amplifies the signal on its way to the controller circuitry.

From a packaging perspective, new high performance heads drive the need to have the preamplifier device closer and closer to the read/write head. In previous generations, the preamplifier device was placed in a traditional surface mount package and mounted to the main electronic board. Subsequent generations moved the preamplifier onto the flex cable. Newer drives will continue to have the preamplifier mounted on the flex cable, as close to the
head as possible. For performance and size reasons, flip chip is the method of choice for the interconnection of the die to the flex circuit. Typical flex assemblies are shown in Figure 1.

Figure 1 – Typical Flex Assemblies.
Typical disk drive flex assemblies show the preamplifier device mounted close to the read/write head.

Assembly Considerations
The flex circuit assembly poses several challenges. First, high accuracy requirements are driven by the use of flip chip. Although a high percentage of today’s flip chip volumes have pitches equal to or greater than 200 microns, the trend is clearly to use tighter pitch arrays in the range of 150 to 180 microns. With such tight pitches, using linear motor die placement systems with placement accuracy of 12 microns or better is required. The following simple analysis provides an accuracy guideline:

Assume that an application presents a solder bump diameter of 75 microns and a pitch of 150 microns. It is well accepted that flip chip solder bumps self-align during reflow and, at a minimum, must touch the substrate pad site at its edge (assumed here to be the same size). This roughly translates into a 50% ball-to-pad coverage requirement to ensure 100% placement yield. This means that the placement may be off-center by 37 microns. Of course, this is a maximum value and such a misregistration may not be acceptable (due to a spacing violation issue for example). As a general rule, a more conservative 75% bump-to-pad coverage is typically used in accuracy models. This roughly translates into a maximum acceptable misregistration of 18 microns for such a design. Anticipating tighter future designs, a machine accuracy of ±10 to 12 microns is a good target.

Final placement accuracy is not only a linear motor issue. Camera systems, vision algorithms, and illumination schemes must be developed to handle such precise placement needs. Illumination, for example, is challenging because of the low level of contrast between the copper circuit and the supporting polyimide flex material. Traditional illumination approaches no longer provide the functionality that permit reliable placement. Effective lighting of the circuit is critical, since even the best die placement machine is paralyzed if the circuit cannot be reliably imaged. Fluxing of the die and high accuracy placement of bumped devices require functionality that is typically found on a flip chip bonder. This functionality includes dip fluxing and the use of waffle pack or wafer die feeding techniques.
Finally, placement of passive 0402 components, as well as the placement of the connector, is also required. The low number of passives (5-10) and the singulated nature of the substrate are not well suited for traditional passive placement equipment solutions.

The solution to these challenges must, of course, take into account the cost sensitivity of this market segment. This requires placement system capability to provide high machine throughput along with the highest flexibility possible.

Die Placement Solutions
Automation strategies addressing these challenges must focus on handling all types of components and the special requirements associated with flip chip, as well as the basic accuracy requirements. And, optimum cost per placement must remain a critical objective.

An example of the basic platform machine used for these types of applications is Universal Instruments’ GSMxs™ Platform, a linear motor machine with a typical accuracy of 12 microns at three sigma. The use of one micron linear encoders and dual Y-axis motors permit this level of accuracy.

To address the imaging issues associated with flex assemblies, traditional lighting systems must be reworked because they are not optimum for these assemblies. An example of this is the recent introduction of a novel illumination module (Reference 3). In this new approach, optimum lighting parameters are determined and controlled to provide optimum contrast between the copper circuit and the underlying polyimide material. Improvements in image contrast are made possible by understanding the light transmission properties of both materials and choosing the lighting parameters to take advantage of these properties.

When using a conventional monochromatic (~660 nm) lighting system, the metal traces of the pad site are virtually indistinguishable from the surrounding polyimide. This is because polyimide is very transmissive to the red light of the illumination module. In the background areas surrounding the metal traces and fiducials, the red light is transmitted through the polyimide and reflects from the metal backing of the circuit. This results in a bright background. The copper features on the substrate also reflect the red light efficiently. The result is a bright feature on a bright background – a low contrast image.

The quality of the image shown in Figure 2 was obtained with the new illumination module equipped with blue LEDs (~470 nm). Since polyimide strongly absorbs the blue portion of the spectrum, the previously bright background is now dark. The copper features on the substrate reflect the blue light efficiently. The result is a significant improvement in image quality.
To address the challenge of high throughput placement of both high accuracy flip chips and passive components using a single placement cell, a unique machine configuration has been introduced. In this mixed head configuration, a high accuracy placement head with four spindles is used for fluxing, die inspection, and placement of the flip chip devices and the connector. In addition, a high speed head with seven spindles is used for the five to ten passive components that are assembled on a typical flex cable. The high accuracy head can handle the most challenging flip chip applications, while the high speed head provides high throughput chip placement. Figure 3 presents a comparison of the number of assemblies obtained using the standard single head and the mixed head configurations.

Figure 3 – Throughput Analysis Table.
Comparison of the number of assemblies/hour or throughput obtained on one placement machine using the standard single head configuration or the mixed head configuration for combined high accuracy and high speed.
Conclusion
The emergence of flip chip as the method of choice for flex assembly has introduced many new challenges to the assembler. These challenges have, in turn, driven equipment manufacturers to develop novel, high volume solutions to meet new requirements. The development of high accuracy equipment, special imaging techniques, and high speed placement solutions have permitted manufacturers to automate the assembly of these circuits in a cost effective manner.

References
(1) IBM web storage web site: www.storage.ibm.com/technology.