Alien Technology Corporation
White Paper

Fluidic Self Assembly

October 1999

Why FSA?

Alien Technology Corp. was formed to commercialize a proprietary technology process, protected by multiple patents, called Fluidic Self Assembly, or FSA.

The technology gives Alien a proprietary position in the fabrication of active matrix display electronic backplanes, the heart of modern flat panel display technology. FSA allows Alien to decouple the production of transistors from the processing of the display materials, eliminating the need for billion-dollar fabs capable of producing transistors directly on a sheet of display glass. Alien can outsource all semiconductor fabrication to mainstream commercial IC foundries, then deposit the known good semiconductor devices over rigid or flexible large surface areas accurately and in an orthogonally correct manner (± 1 micron).

With FSA, Alien can build active matrix electronic backplanes on rigid (glass or plastic) or flexible (polyester, polyimide, polycarbonate, etc.) substrates. Active matrix backplanes fabricated with the FSA process are capable of lowering the cost and enhancing the performance of all known flat panel display technologies, including LCD, PDLC, electrophoretic, ferroelectric, cholesteric, organic LED, electroluminescent, up- and/or down-converting phosphors and field-emission displays.

FSA simplifies the transition to fully automated in-line reel to reel (web) processing on a continuous flexible substrate. Web processing is a high-volume, continuous technique, far more efficient than the batch-oriented processes used in existing active-matrix LCD (AMLCD) fabs. Together, FSA and web processing offer powerful advantages over traditional processing on rigid glass substrates:

- Reduced manufacturing facility investment
- Reduced material and manufacturing costs
- Increased manufacturing through-put
- Increased production yields
- Manufacturing line flexibility - flexible, conformal or rigid displays in numerous display technologies can be built on the same line
- Improved display performance for all kinds of displays
- Genuine potential for making very large, light weight, low power, wall hung televisions

How FSA Works

The basic principles behind FSA are very simple. In the FSA process, specifically shaped semiconductor devices ranging in size from 10 microns to several hundred microns are suspended in liquid and flowed over a surface which has correspondingly shaped "holes" or receptors on it and into which the devices settle. The shape of the devices and of the holes is designed so that the devices fall easily into place and are self-aligning. Alien has successfully demonstrated the assembly of tens of thousands of devices in a single process step.

The FSA Process

FSA involves the following steps:

I. The process begins with the use of single crystal silicon wafers containing anywhere from hundreds to millions of microelectronic devices. The devices can be as simple as individual transistors or as complex as integrated circuits. Alien Technology uses large commercial semiconductor foundries to produce these microelectronic devices on standard CMOS IC processes.

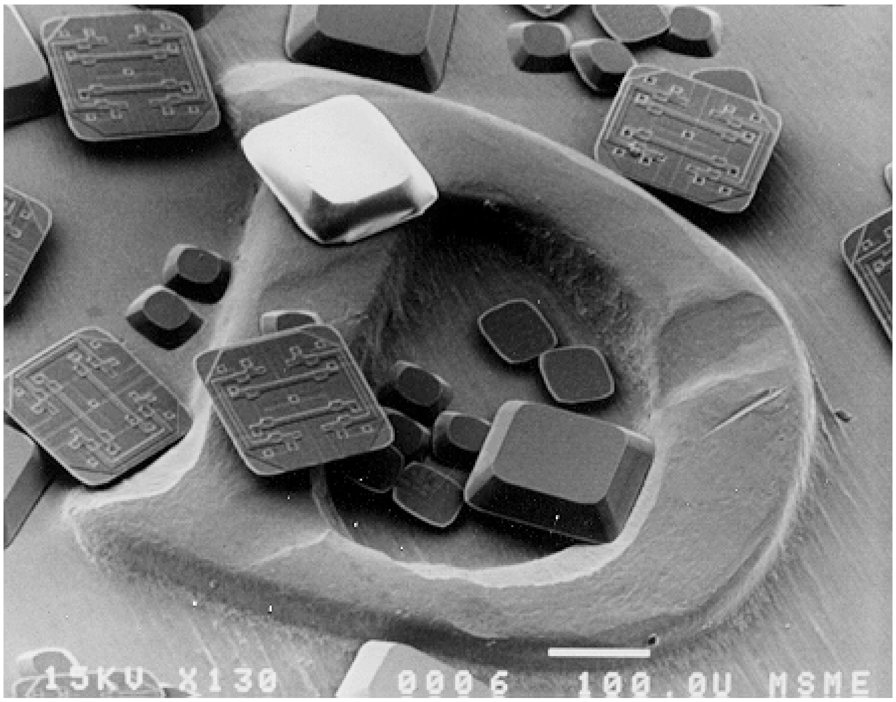

Figure 1. Microphotograph of individual Nanoblocks on the surface of a dime

II. In the next step each separate microelectronic device is freed from the wafers through an etching process which effectively slices the silicon wafer into thousands or millions of separate functional devices having specific three-dimensional shapes. Alien has trademarked the term “Nanoblock” to describe the devices freed from the silicon wafers. The process of etching, shaping, and freeing the Nanoblocks is a patent-pending proprietary process.

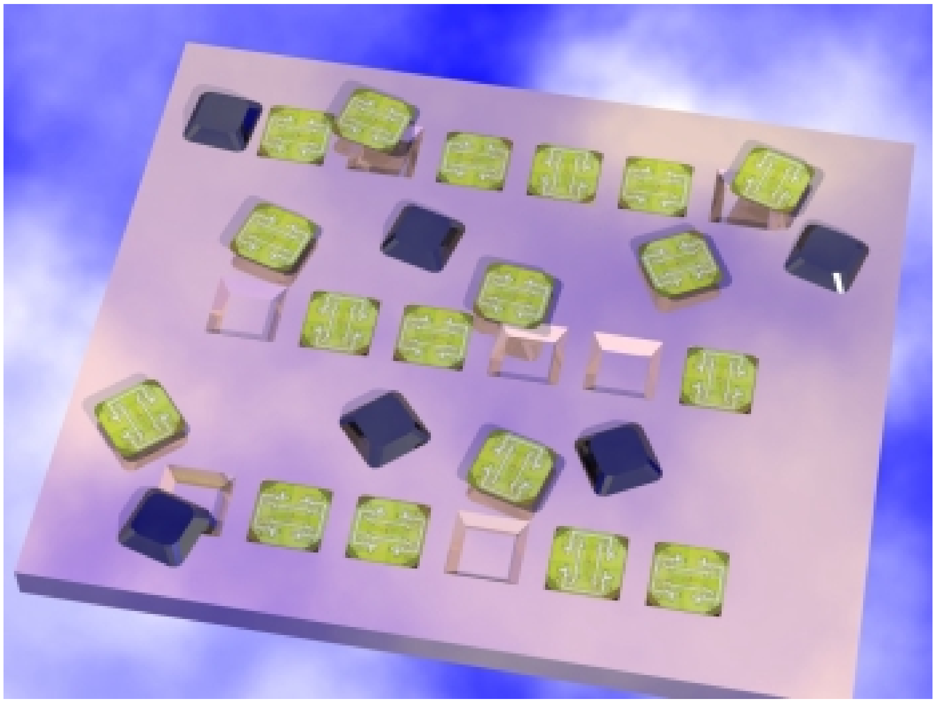

Figure 2. Artist's rendition of Nanoblocks falling into substrate holes.

III. Separately, the underlying substrate – to which the Nanoblocks will be bonded – has holes punched, etched, or laser drilled into it. These specifically shaped holes correspond to the microelectronic devices, or Nanoblock shapes. This is also a patent-pending proprietary process.

IV. The Nanoblocks are then suspended in a fluid, which is flowed across a previously prepared substrate surface. As the Nanoblocks pass over the substrate surface they drop into the correspondingly shaped holes.

This step is the heart of Alien's patented process. It allows all of the semiconductor circuitry for an active matrix display to be produced in IC fabs. It also gives Alien freedom to select the most efficient mass production process in manufacturing today, reel to reel web processing. Unlike conventional active matrix display manufacturers, Alien is not constrained to processing inferior (polysilicon or amorphous silicon) semiconductor devices on glass.

V. The Nanoblocks that did not assemble themselves into holes in the substrate surface are removed from the fluid, cleaned and then re-suspended into cleaned fluid to be flowed once again over another substrate. In this way the Nanoblocks and suspension fluid continue to be "recycled ".

VI. In the last step, the Nanoblocks that did self-assemble into the holes in the substrate are electrically connected via standard metallization techniques to create the final integrated system, in this case as an active matrix display with fully integrated on-board drive and control logic.

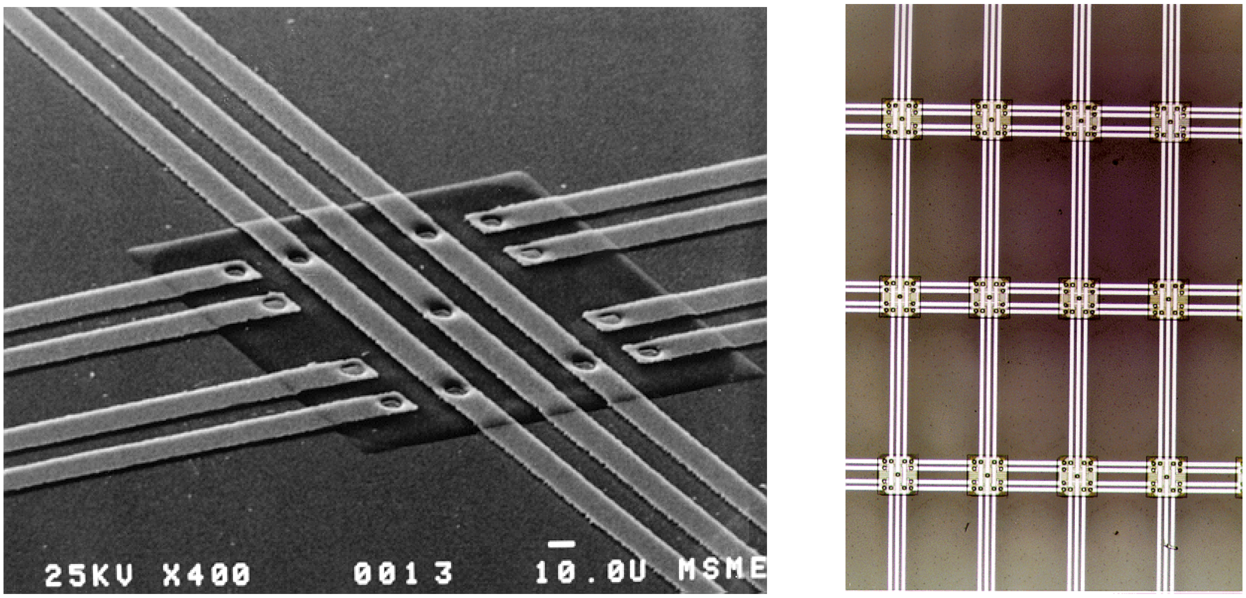

Figure 3. Microphotographs of a passivated metallized Nanoblock and a 3X4 subsection of a metallized array of Nanoblocks on glass substrate

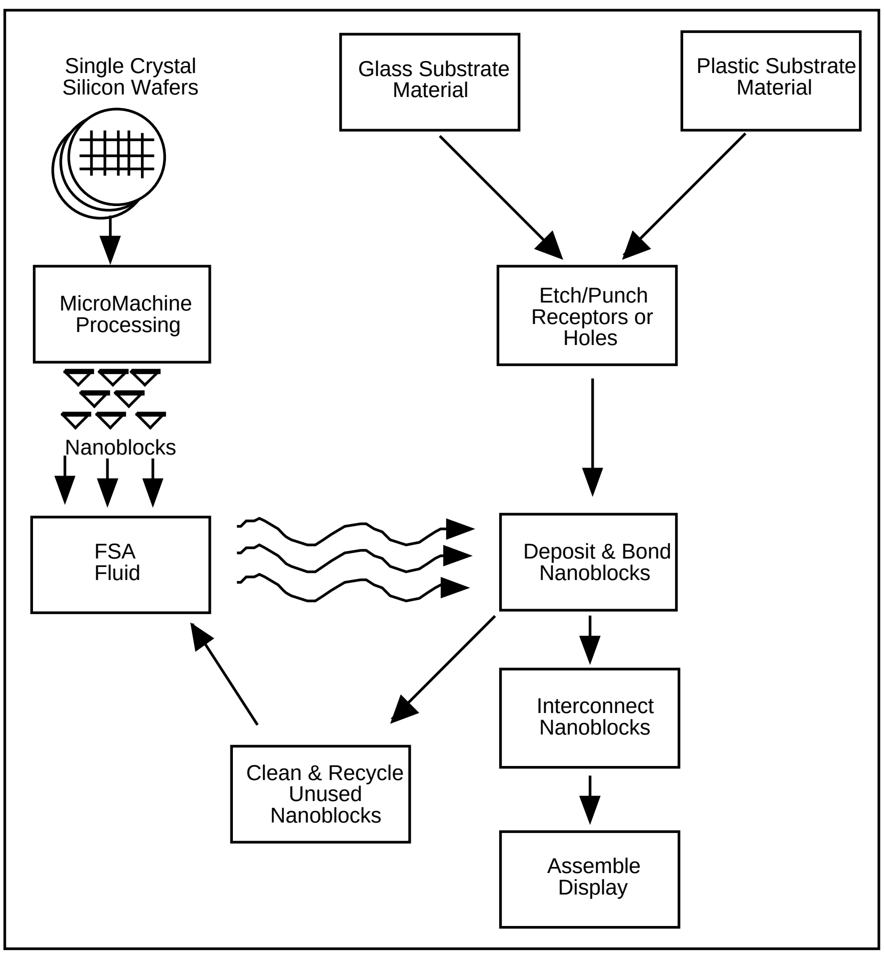

Figure 4. The FSA Process

FSA Advantages

The FSA process has major advantages as a method for producing electronic displays:

a) High Reliability and Manufacturing Yields.

A primary advantage of FSA is that it decouples the fabrication of active devices from the large-area substrate fabrication. The active devices or Nanoblocks are fabricated using common CMOS IC processes, and can be tested prior to being freed, or micromachined, from the wafer and assembled into the display substrate.

The fact that the Nanoblocks are tested before separation from the silicon wafer means that all Nanoblocks, which are later bonded onto the substrate surface, will be fully functional devices. This translates into both a high reliability display and high manufacturing yields. Furthermore, Nanoblocks can be made with redundant active devices and redundant row and column drive circuitry, thus providing backup should one of the devices later become inoperable.

b) Substrate Material Flexibility

FSA substrates can be made from any number of materials, including glass, plastic, silicon, etc. The substrate can be selected based on any number of desired properties. When manufacturing displays using the FSA process, the choice of substrate materials is not limited to rigid materials compatible with high temperature semiconductor fabrication processes. This opens up the possibility of producing displays that can be flexed or bent while in use, and are light in weight.

Reel to reel web processing on flexible substrates also enables the efficient fabrication of active matrix displays of varying shapes and contours. Automotive dashboards provide one example where such a capability is desirable. With traditional display technologies, every car will need to be equipped with me-too flat, rigid active matrix displays. With conformable displays, automakers like Porsche and Mercedes will have the option of maintaining their signature contoured dashboard designs.

c) Manufacturing Speed

The FSA process is a fast process for placing dozens or millions of microelectronic devices into an array. It works automatically to place millions of Nanoblocks in minutes or thousands of Nanoblocks in seconds.

d) Low Cost

The FSA process relies on mainstream VLSI semiconductor technology. FSA uses high quality tested Nanoblocks, maintains high manufacturing yields, allows for the use of many different display substrate and Nanoblock materials, and provides a proprietary method for low cost, high volume manufacture of active matrix displays. Furthermore, the FSA process can be integrated easily into existing display manufacturing lines, with very little new equipment required.

e) Nanoblock Material Flexibility

Nanoblocks can be fabricated in numerous materials, such as silicon, silicon-germanium, gallium arsenide, indium gallium phosphide or whatever, depending on the desired functionality for the Nanoblock. Nanoblocks of differing sizes, shapes, materials and functionality can be readily mixed and matched on a substrate using the FSA process. And composite material Nanoblocks can be assembled using the FSA process – e.g., smaller LEDs or VECSELs can be FSA'd into somewhat larger silicon drive and control circuit Nanoblocks, then the composite Nanoblocks can be assembled onto a large area substrate.

Applications

Most of the above discussion focuses on the advantages of FSA in the manufacturing of various kinds of flat panel displays. However, the use of FSA is not limited to this sole application. As a generic cost-effective solution to the problem of creating large-area fine-scale assemblies, FSA has a large number of potential manufacturing applications.

For example, FSA can be used to create displays using actively driven Light Emitting Diodes (LED) FSA'd into silicon drive/control Nanoblocks. It can be used to fabricate hybrid circuit assemblies for cellular phone subsystem integration. And FSA could be used to cost-effectively provide a high-performance optical interface between RAMBUS memory modules and Xeon Pentium II or Merced processors.

LED displays (monochrome or color) can be produced more economically with FSA. A single LED wafer could be micromachined into tens or hundreds of thousands of LED Nanoblocks and placed onto a suitable substrate using FSA. This would create an LED display array, which is prohibitively expensive to build with existing techniques.

Vertical Cavity Surface Emitting Laser (VECSEL) devices can be FSA assembled into silicon circuits in place of conventional metal pad interconnects. These optical VECSEL I/Os have tremendous bandwidth capacities orders of magnitude higher than conventional wire bond I/Os, allowing the large complex silicon ICs to run cooler and dissipate less power in lower pincount, less expensive packages.

Finally, FSA can be the linchpin in making some promising new display technologies a reality. With FSA, Organic Light Emitting Diode (OLED) and up- or down-converting phosphor (U/DCP) displays have a much better chance of achieving competitive economy, performance, and manufacturability in a reasonable timeframe. Those technologies show promise for making the long-sought wall-hung High Definition Television (HDTV) possible, but require active-matrix drive characteristics that amorphous or polysilicon processes cannot effectively provide. FSA, using single-crystal Nanoblocks, may be the breakthrough needed to make those technologies useable.