Realizing Complex Microsystems: A Deterministic Parallel Assembly Approach

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ABSTRACT

The push towards miniaturization has created substantial interest in microelectromechanical systems (MEMS). To date, most of the developments regarding MEMS technology have relied on monolithic fabrication and integration. The monolithic approach has successfully produced various miniature technologies; however, most of these miniature technologies are essentially discrete devices or, at best, simple systems such as pressure sensors and accelerometers. Truly complex systems, by definition, are a combination of independent but interrelated elements that, in totality, function as a unified entity. Computer-controlled, parallel assembly of micromachined components promises to drive the miniaturization wave by enabling the manufacture of unprecedented complex microsystems. Described in this paper is a deterministic parallel assembly approach that uses silicon MEMS components, such as end-effectors, connectors, and sockets, integrated with high precision robotic systems.

Keywords: MEMS, microassembly, parallel assembly, microsystems

1 INTRODUCTION

Many of the current, commercially-available MEMS devices such as pressure sensors and accelerometers rely on monolithic fabrication methods. As the drive towards miniaturization continues, more complex devices will be developed which will push the limits of monolithic fabrication methods and may require the heterogeneous assembly of materials. Assembly of micro components will complement monolithic approaches and enable the fabrication of complex microsystems comprised of dissimilar materials and structures fabricated from both MEMS and non-MEMS processes.

Microassembly can be subdivided into two broad categories – stochastic assembly and deterministic assembly [1]. Stochastic assembly methods accomplish the parallel placement of components through self-assembly mediated via global, external forces such as fluid flow [2] or vibratory agitation [3]. Each part randomly moves across the substrate which contains sites, such as etched wells, where the parts are desired to be placed. Both the parts and the placement sites must be designed such that the desired placement and orientation of each part is achieved. In contrast to the random nature of the stochastic approach, deterministic assembly incorporates the direct placement of every part in serial or parallel fashion [4], [5]. Each component is picked up and placed into its desired location so that the placement of each component is known.

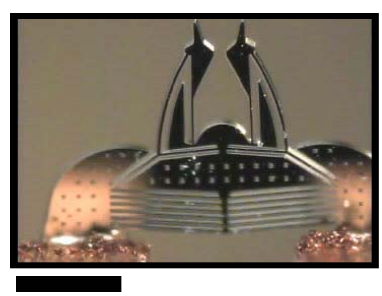
Zyvex is developing a deterministic parallel assembly approach that uses silicon MEMS components, such as end-effectors, connectors, and sockets, integrated with high precision robotic systems. The end-effectors are deep reactive ion etched structures that are manipulated via robotic systems and are used to pick the MEMS components from the substrate and place them in their respective sockets (which are also micromachined within the substrate). The sockets are designed for mechanical connectivity and can be metalized to provide electrical connection to the component.

2 MICROASSEMBLY TOOLS

The tools required for microassembly are end-effectors, connectors, and sockets. All of these tools can be precisely manufactured using MEMS processes. End-effectors including grippers and jammers are used to pick up the various components. Incorporated with each of the pickable components are connectors designed to couple with a specific end-effector. Sockets within the substrate are designed to accommodate the connectors associated with each of the pickable components. All of these tools and their associated components are designed with standard MEMS and/or integrated circuit (IC) layout software. The computer-aided design (CAD) layout not only contains the tool and component designs, but also provides the necessary data to determine the precise placement of all of the components. This data can be used to automate the robotic assembly system.

2.1 End-effectors

An example of an end-effector used to pick and place components is the microgripper shown in Figure 1.



300 μm

Figure 1: 50-μm thick, electrothermal microgripper.

The microgripper is fabricated using deep reactive ion etching of silicon and uses electrothermal actuation. The grippers can be fabricated with a range of opening sizes and can be designed to either open or close when power is supplied. All of the end-effectors are designed to couple with connectors, described below, that are built into the MEMS components. Grippers can also be designed for non-MEMS components such as wires and coils.

2.2 Connectors

To facilitate assembly, the MEMS components are designed with built-in compliant connectors that are geometrically and mechanically symmetric which results in self-centering of the assembled parts. Examples of connector structures are shown in Figure 2. The thin, angled beam attached to the top of each part is a breakable tether used to hold the components in place until assembly.

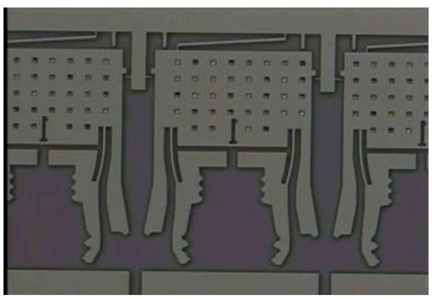


Figure 2: 50-µm thick connector microstructures.

Connectors are designed to accommodate the desired end-effector (gripper, jammer, etc.) which will be used to pick up the attached component and can be metalized for improved electrical connectivity. MEMS components including micromirrors, electrostatic plate deflectors, bent-beam actuators, and thermal bimorphs have all been fabricated with attached connectors.

2.3 Sockets

Once the component attached to a connector is picked up with the appropriate end-effector, the component is then placed into its respective socket located within the substrate. An example socket is shown in Figure 3.

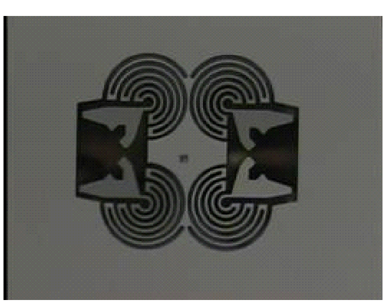


Figure 3: Micromachined socket.

Incorporated with the socket shown above are compliant spring structures which further enhance the self-aligning capability of our microassembly approach. Upon release of the MEMS component within the socket, the connector and socket equilibrate and stabilize to their designed positions due to their compliance. The self-alignment capability allows for precision part placement independent of the initial robotic placement of the part. Metalization of the sockets can be performed to further facilitate electrical connectivity. A final placed part is shown in Figure 4.

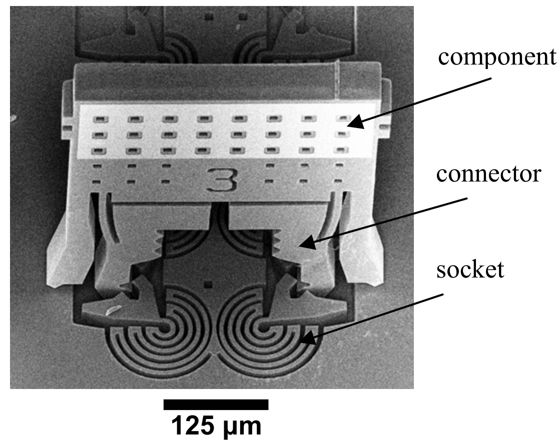


Figure 4: A MEMS component placed within a socket.

2.4 Robotics

Our current robotic system consists of a five degree of freedom configuration and is shown in Figure 5.

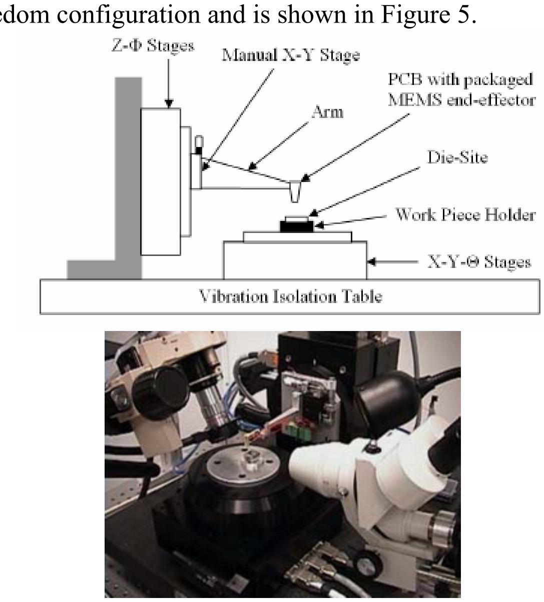


Figure 5: Microassembly robotic system.

Three stages provide for XY and theta motion of the work piece substrate. A Z and phi stage provides motion towards and away from the substrate and rotation about an axis parallel to the XY plane of motion. End-effectors are attached to the end of the arm which can rotate about the phi axis parallel to the XY plane. All five stages are driven by a closed loop control system providing a one micron precision over the range of travel for the linear stages. The system is computer controlled via a GPIB interface and motion sequences can be programmed with a scripting language allowing for automated assembly of micro devices. For instance, the script can be derived from the CAD layout which contains the designs for the MEMS components, connectors, and sockets.

3 PROCESS FLOW AND MICROASSEMBLY

The MEMS components are fabricated on silicon-on-insulator (SOI) wafers. The components are built within the top, thinner layer of silicon (the device layer) and are tethered to fixed structures built within the same layer. The buried oxide is used as a sacrificial layer which is removed during the final process steps. An example of a SOI MEMS fabrication process is shown in Figure 6.

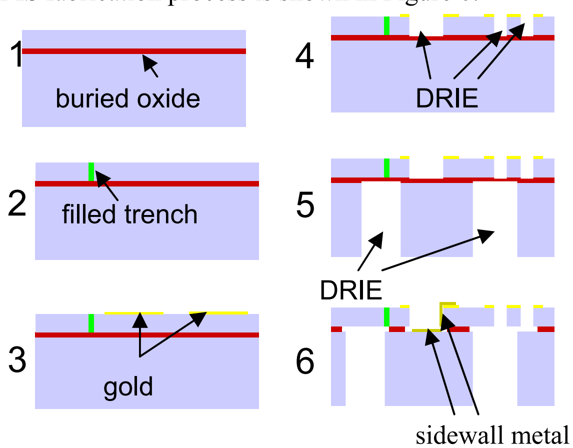


Figure 6: Example SOI MEMS fabrication process.

After the buried oxide is removed and the wafer is diced, the MEMS components to be assembled are de-tethered from the substrate to fully release the components. A simple tether is shown previously in Figure 2. The tethers are broken using an end-effector attached to the robotic arm. Automatic de-tethering can be accomplished by programming the sequence with a script derived from the CAD layout. Each component is then picked up off the substrate by the MEMS end-effector, rotated into position, and inserted into the desired socket. Using the Zyvex-designed MEMulator software, an emulation of the microassembly process is shown in Figure 7.

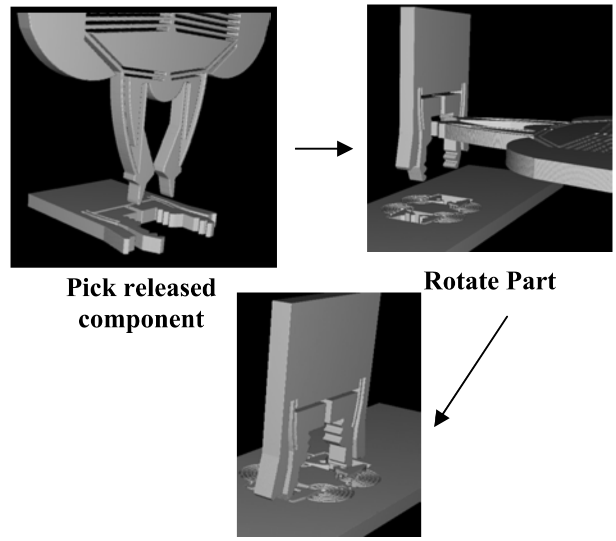


Figure 7: Emulation of the microassembly process.

4 PARALLEL ASSEMBLY

The parallel assembly of components has the potential to achieve higher manufacturing throughput over serial assembly. The difference with parallel assembly is the need to array the end-effectors onto the robotic arm. Furthermore, alignment of the connectors and sockets becomes more challenging and requires more complex robotic control schemes. Parallel assembly examples using 1X2 and 1X4 end-effector arrays are shown in Figure 8 and Figure 9, respectively.

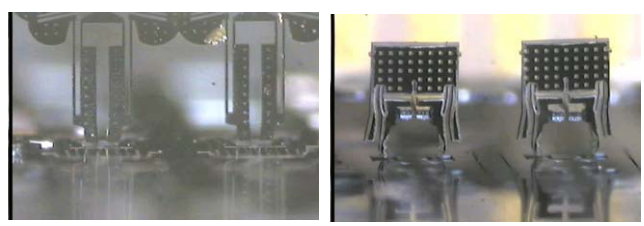


Figure 8: Parallel assembly using a 1X2 array.

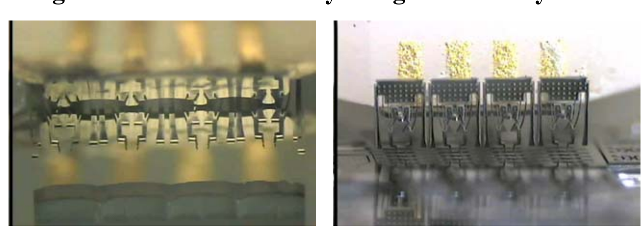


Figure 9: Parallel assembly using a 1X4 array.

5 MICROASSEMBLED DEVICES

The following are examples of devices that have been assembled using our microassembly tools and robotic system. Figure 10 depicts an assembly of four electrostatic deflector plates which make up a quadrupole structure for charged particle manipulation.

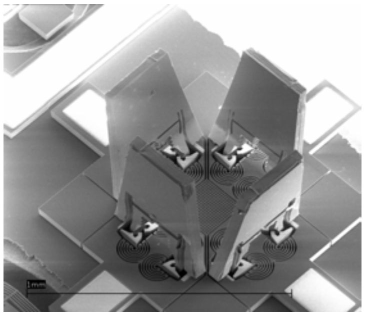


Figure 10: A microassembled quadrupole.

A variable optical attenuator is shown in Figure 11, comprised of three fixed micromirrors and a single, movable micromirror. The movable mirror is placed within a socket attached to electrothermal actuators.

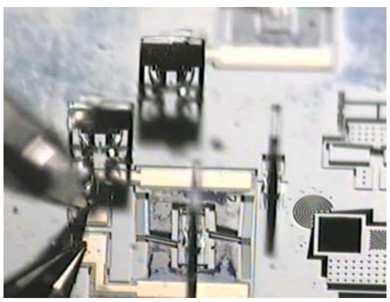


Figure 11: Micromirrors arranged as a variable optical attenuator. Bottom mirror is positioned within a movable socket which rotates the mirror.

Finally, an example of the heterogeneous assembly achievable with our deterministic approach is the variable inductor shown in Figure 12. A copper coil is shown to the left. A silicon micromachined linear stepper motor is located to the right of the coil. Attached to the stepper motor and located within the coil is a nickel-iron core which is manipulated via the stepper motor.

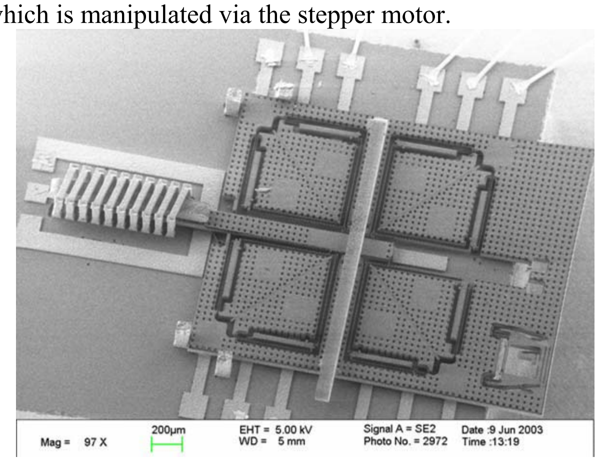


Figure 12: A microassembled variable inductor.

6 CONCLUSION

Several benefits over monolithic fabrication and stochastic assembly are realized when utilizing a deterministic microassembly approach. In comparison to the random placement nature of stochastic assembly, directed placement of each component is achieved with the deterministic approach. Such directed placement enables full tracking of each component and is amenable to “known good die” manufacturing. Another benefit of the deterministic approach is the ability to assemble heterogeneous components within a single microsystem. For instance, components made from various MEMS processes or even different materials can be precisely assembled together to form a truly complex microsystem. Due to the versatility of the deterministic parallel assembly approach described herein, numerous applications of microsystems can be realized including fiber optic components, high frequency devices, portable chemical and biological detection systems, and miniature high performance laboratory and industrial instrumentation.

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