Microrobotics

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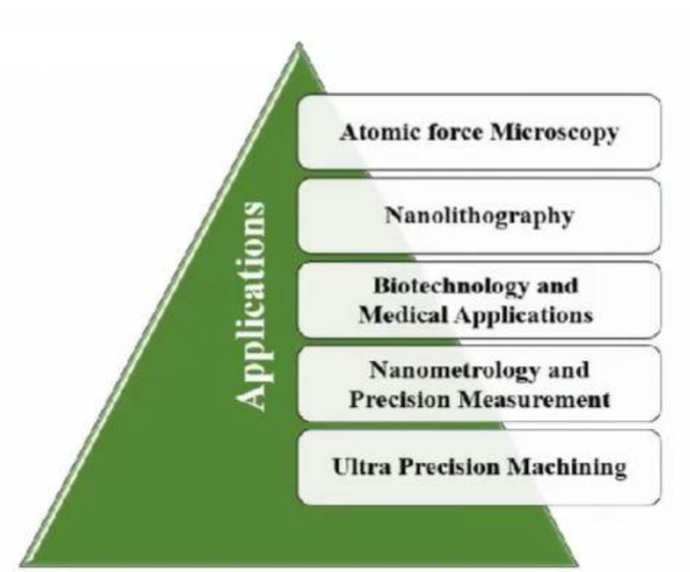
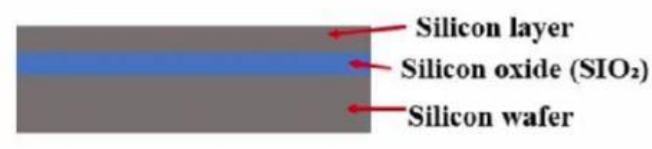
Lecture No- 45

Microsystems for Microrobots (Manipulation) - Module 05

We were discussing this microsystem for micro robotic-related applications, more focused on the manipulation-related aspect in the current modules. We have discussed different methodologies that are involved in magnetic, acoustic, and optical tweezers in detail. We have also seen an AFM and how AFM has been utilized as a robotic system. In today's lecture, we will discuss the integrated nano tool carrier. A nano tool carrier is a high precision device designed to hold and manipulate nanoscale tools for microfabrication and material processing. The major nano tool carriers used in the fabrication and characterization are the MEMS-based tool carriers and the vacuum-based tool carriers.



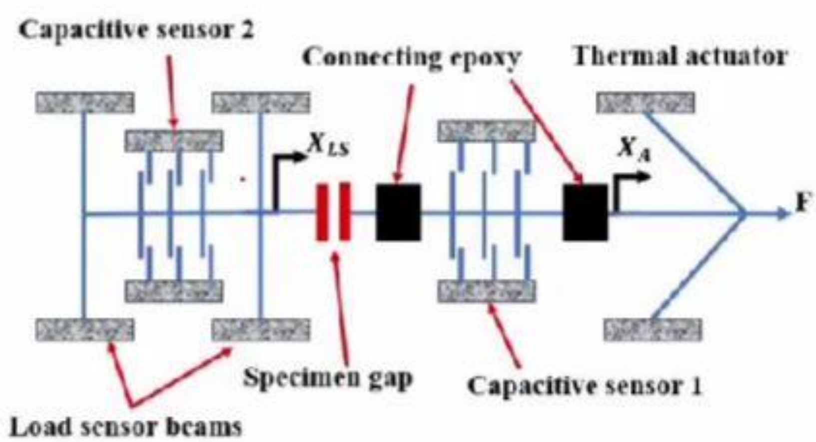
Such kinds of nano tool carriers are efficiently used for atomic force microscopy, nanolithography, biotechnology, medical applications, nano metrology, precision measurements, and ultra-precision machining. Firstly, let us consider the MEMS-based nanotool carrier. The MEMS-based nanotool carrier consists of silicon on insulator, which is a three-layered structure comprising a silicon layer, silicon oxide, and a silicon wafer. Over the silicon wafer, we have the silicon oxide and the silicon layers.



Silicon on Insulator

They are fabricated as MEMS devices by using silicon on insulator, i.e., SOI. The final structure is created by D-RIE silicon etching, which is a silicon etching and an SiO2 etching process. Now, considering a microcapacitive sensor, this device provides the means for actuation and sensing via electrical signals.

The overall construction of the microcapacitive sensor is a kind of comb drive actuator. Multiple electrodes are placed and appropriately connected to a capacitor arrangement. The assembly consists of two different capacitive sensor assemblies. The figure shows the micro capacitive sensor assembly, including sensors 1 and 2. Both the capacitive configurations have a load sensor beam.

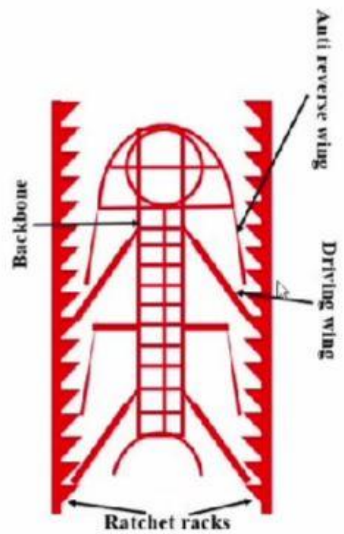


Capacitive sensor

So, the load sensor beams are connected to the capacitors in the arrangement. In the middle of the sensor, there is a specimen gap. This specimen gap will act as a kind of reference gap. The specimen gap is used for observations in TEM. Then, in addition to this, we also have thermal actuators. So, these thermal actuators are used efficiently for compensation. So, in the case of this microcapacitive sensor, the device provides the means for actuation and sensing via electrical signals. It consists of a thermal actuator, two interdigitated capacitive sensors, a load sensing beam, and a specimen gap for observation in the TEM. The MEMS devices are fabricated using a kind of SOI-MUMPS process with MEMS cap. The monocrystalline silicon structural layer is patterned to create the required component of the device, while the substrate is patterned and etched from the bottom side to the oxide layer to create a kind of free-standing structure for TEM imaging purposes. The thermal actuator consists of 10 pairs of inclined beams, which provide a driving displacement to the device by resistive heating. The displacement of the thermal actuator is controlled by the input voltage applied across the beams, which is recorded with reference to the capacitive actuator. Also, a very large heat sink is provided between the thermal actuator and the nearest capacitive sensor. Here, the distance of the actuator from the specimen gap is on the order of 1.5 mm. This heat sink limits the temperature increase near the specimen gap to 0.07 degrees Celsius per 10 nanometer displacement of the thermal actuator, which means the sink ensures that if the displacement is 10 nm, the temperature rise of the capacitor should not go beyond 0.07 degrees. The heat sink absorbs the additional heat. There are 2 air gaps on each side of the capacitive sensors filled with epoxy glue.

So, these rigid epoxy bridges provide electrical isolation between the thermal actuators, capacitive sensors like CS1, which is nomenclated as CS1 and CS2. One of the epoxy bridges connects CS1 to the thermal actuator, while the other connects to the specimen gap. CS1, therefore, measures the displacement of the thermal actuator XA. The other capacitive sensor, CS2, is rigidly connected to the load sensor and, hence, measures the displacement of the load sensor XLS. This kind of configuration is mainly meant for a type of nano tool carrier with micro capacitance as a base.

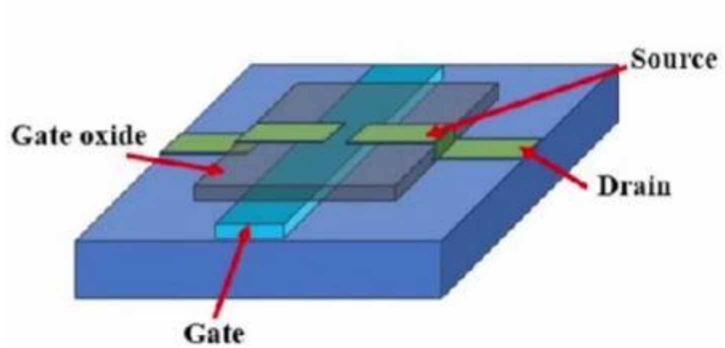
Now, let us take another example, which is a kind of microcontainer and a microtransport mechanism. In this microcontainer, the ratcheting structure converts a reciprocating displacement of an electrostatic comb drive actuator to continuous, unidirectional, straight, and turning movement of the micrometer scale object. The force induced by the electrostatic comb drive actuator pushes the ratchet rack inwards, causing the driving wings to move inwards. So, this is a kind of driving wing that has a reverse wing or a backbone arrangement. So, this ratchet rack will try to push the driving wing, and the reverse wing will be appropriately actuated to achieve the required characteristics.



Micro container/Micro transportation mechanism

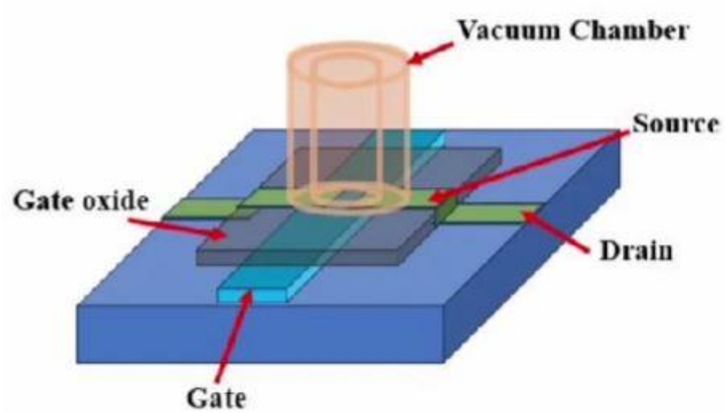
So, this is a kind of microcontainer which has more to do with micro transportation mechanisms. It is a kind of mechanical system that is being deployed for movement or for the collection. Here, the force induced by the electrostatic comb drive actuator pushes the ratchet rack inward, causing the driving wing to move inward. As a result, the container is moved forward, and when the force is removed, the container will not move backward due to the ratchet mechanism of the anti-reverse wind. So, this is a kind of a ratchet wing mechanism which will be helpful for us to give an incremental displacement to the system.

Now let us discuss this vacuum-based carrier. It consists of a gate arrangement, a gate oxide, a source, and a drain arrangement. The vacuum-based nano tool carrier is a precision system that is designed to transport, position, and manipulate a nanoscale tool or objects using a vacuum source. Examples include vacuum-based tunneling transistors, nano vacuum tubes, or vacuum grippers, etc. The figure shows a nanogap vacuum tunneling transistor that is fabricated on a silicon substrate with thermally grown SiO_2.



The gate electrode is patterned by electron beam lithography. The charge dissipating agent was coated to minimize the electron beam charging effects for the nano gap. So the gate materials of chromium and gold are deposited using a thermal evaporation system and a lift-off. We have discussed related to lift-off in previous lectures. We have discussed micro 3D printing technology, which is considered to be one of the key aspects in fabricating such a vacuum-based system that has potential applications in nano tool carrier-related applications.

In the nano vacuum tunneling transistor discussed here, SiO2 was used as a gate oxide, and it was deposited using a type of plasma enhanced chemical vapor deposition (PECVD) process. The PECVD process gives a high-quality crystal based on our requirements. Then we have a source and a drain electrode which are also patterned using EBL. It is used to obtain a gap that is several tens of nanometers in size. For the electrode material, tungsten was deposited by a magnetron sputtering system and then lifted off, so that you can fabricate a kind of layered structure on this particular system.

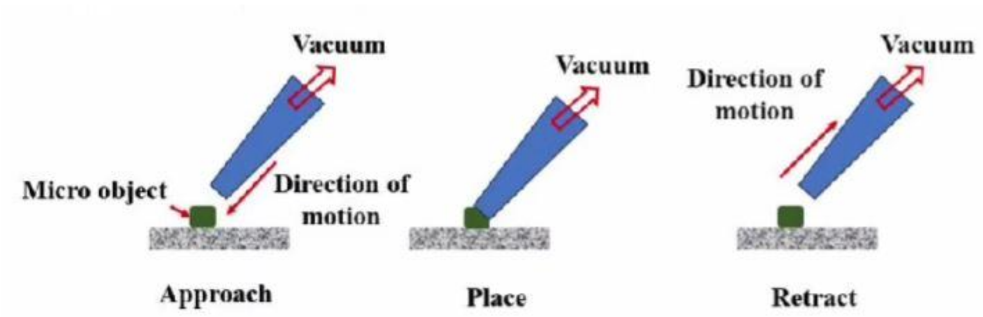


In addition to this, all contact pads of the electrodes were fabricated using a kind of photolithography process and deposited using the same materials and methods. In this particular process, the electrodes are fabricated in such a way that the photolithography and the deposited layers use the same material and are established in a particular fashion for the desired application. Now an extended version of this vacuum-based carrier is called a nanovacuume tube. It has a similar configuration, where there is a drain, source, gate,

gate oxide, and a vacuum chamber. This vacuum chamber is used as a kind of nano carrier tool. The vacuum chamber is a kind of tubular structure on top of the vacuum transistor. A wall of the vacuum chamber is silicon oxide deposited with PECVD. Nano-scale holes are patterned for the vacuum cylinder using electron beam lithography. The vacuum chamber is sealed by a thin film deposition using a thermal evaporation system, and then aluminum is used as a vacuum sealing material with a thickness of 400 nanometers. Due to the photovoltaic and photoelectric effects, semiconductor devices suffer from abnormal behavior when exposed to light.

Even semiconductor devices can be damaged by a kind of high-energy light. So, these nano vacuum tubes can effectively seize the damage and can be used for a type of application for this nano carrier tool. So, this is one combination where a nano vacuum tube has been effectively used to seize the damage.

Now let us also discuss the next part of vacuum-based carriers, which are vacuum grippers. These vacuum grippers are a kind of glass pipette and are either made from soda glass or borosilicate glass tubes. Grippers are produced by heating and pulling the hollow tube simultaneously. In the given figure, we have a tube in which a vacuum is created. This vacuum is used for moving a micro object back and forth. The direction of the movement of this micro-object is well manipulated with this vacuum. The motion includes three different kinds of operations, which are represented in the figure.

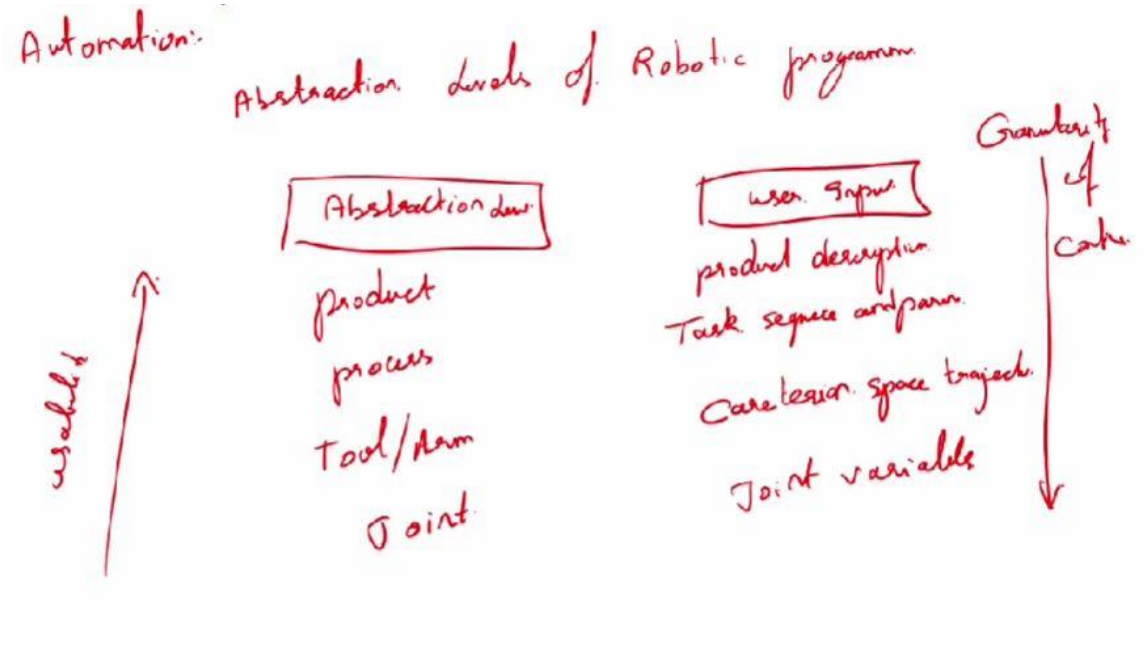


The first operation is an approach operation where the vacuum tube is brought near the micro object and then suction is initiated. This motion is termed as approach behavior where the vacuum tube is brought near the micro object. When a tube is placed near a micro object, there will be suction to hold the particular object. The suction is used for picking and placing the micro object. Finally, there will be a retraction that releases the particle from the vacuum tube. So these are some kinds of combinations that are being exhibited in relation to a different manipulation condition, the micro-manipulation condition. Now let us discuss one of the key aspects, which is the autonomous programming of these micro assembly robots. We have seen several configurations of these micro assemblies; for example, we started with the AFM and had an interaction with an acoustic-based system. We have studied the different methodologies involved in it, starting from a gripper, a magnetic assembly, magnetic micro robots, grippers, light, optical tweezers, acoustic fields, and direct self-assembly. In all these cases, there is a magnetic field, an electrical field, or another kind of field. Based on the field, the manipulation is appropriately exerted. Either your manipulation is on a micro scale or a nano scale; appropriately, your exertions are being controlled. We had some discussions about the AFM. The AFM is a kind of characterization tool that effectively uses micro-manipulation aspects. So in the case of an AFM tool, we have seen different modes.

The overall functionality of the AFM, the overall characteristics of the AFM, how these AFMs are deployed for different applications, and the overall feedback systems that are being deployed in AFM-related applications have also been discussed. Now the usage of this AFM in the form of nano and fiber pulling is also discussed, and there are other modes of systems that have also been discussed, such as polymer drawing, flame or heated taper drawing. We also had a discussion about gas absorption-based spectroscopy, the application of these fibers in gas absorption-based spectroscopy, Mach-Zehnder interferometers, and in the case of gratings, resonators, etc., couplers. We had a good discussion on optical tweezers, especially on optical manipulation.

What are the different configurations of optical manipulation? This is a conventional optical tweezer system with acoustic deflection, and we also have a holographic optical tweezer. As an integrated nano tool carrier, we have also discussed micro and nano tool carriers. Another kind is vacuum-based carriers; then we have tunneling-based carriers. The third one is a mechanical transportation-based mechanism that is used, and then there are certain kinds of capacitive sensors discussed. We also have a vacuum arrangement that is used for appropriate suction. Now let us discuss a case study that focuses on the autonomous programming of micro-assembly robotics. Due to the strides in the miniaturization of systems and the growing field of optical technologies, micro assembly is becoming an interesting and important topic. So, micro assembly is characterized by the challenging process that requires sub-micron level position accuracy regardless of the modeling and calibration errors in the manipulator system. So there is a need to pursue the automation of this process or to have an understanding of the automation of this process, which requires not only profound expertise but also a highly trained person in the field of programming. We will discuss the autonomous programming combined with an intuitive programming approach using intelligent and self-learning algorithms and how it is being demonstrated in actual conditions.

First, we will discuss the abstraction level of robotic programming. It is classified into two parts: one is the abstraction level, and the other is the user input. So, under the abstraction level, we have the product, process, tool arm, and the joint. Under the user input, we have the product description, the task sequence and parameters, a Cartesian space trajectory, and the joint variables. Abstraction levels and user input are classified based on usability and granularity of control.

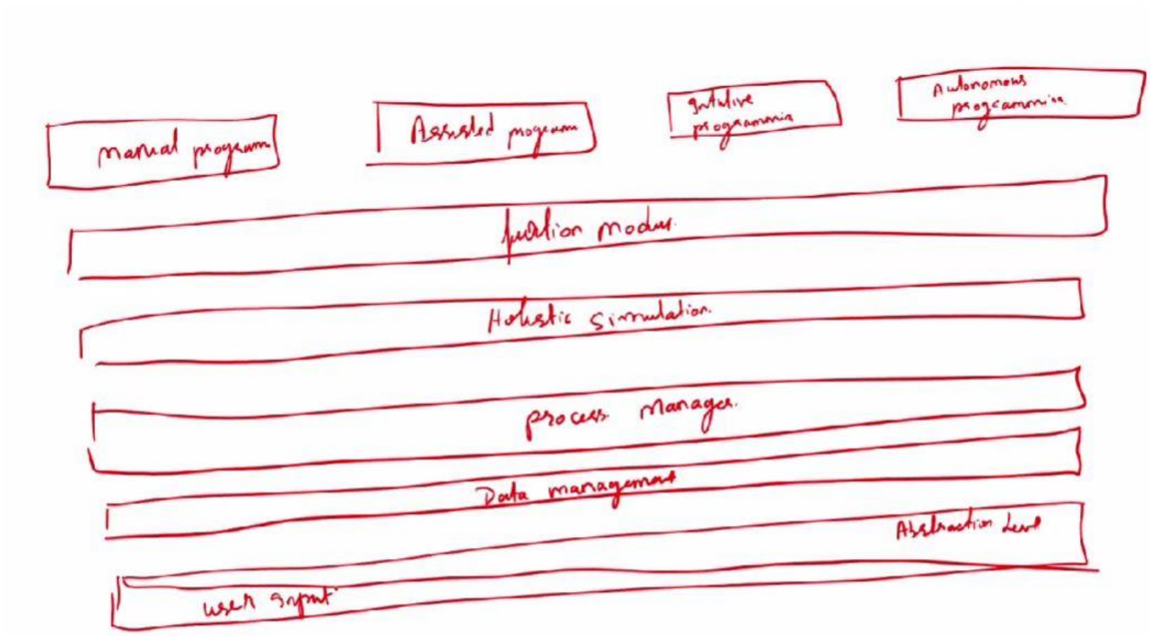


So, considering the programming of the industrial robot, it traditionally requires a high level of expertise, which makes setting up a new process a time-consuming and expensive endeavor. However, several approaches have been made to make robotic programming more intuitive or even autonomous. So the principal approach entails elevating the abstraction level in programming to enhance intuitiveness for the user and subsequently diminishing the need for extensive programming expertise. So by controlling these parameters, we can have control over the programming. Within the domain of intuitive programming, emphasis is placed mainly on the abstraction level of the process.

So, here skill serves to encapsulate the textual code. The skill is sometimes also called the function modules or functional blocks. Representing the basic functions of the robot, such as picking and placing or gripping, ensures that the user inputs are at the task level being established here. Similarly, when we consider the simulation framework for micro assembly and task programming, there are different methodologies being deployed with reference to industrial robotics and the programming of micro assembly robots. This still requires expert knowledge, along with a current state of intuitive programming for a micro assembly robot.

Now, consider a kind of autonomous microassembly robot. Let us discuss the key parameters or the key aspects that should be planned. Let us consider the different programming configurations for a microrobotic application. One is a kind of manual programming; then we have assisted programming, intuitive programming, and autonomous programming. The programming is decided on the basis of four different sets, which contribute to it.

One is called the function module, the other is a holistic simulation, the third is the process manager, and the fourth is the data management. So, in this particular aspect, we have two different inputs: one is the abstraction level, and the other is the user input. Now we will discuss their applications with reference to their overall characteristics. So as far as this particular case is concerned, the current approach, not only from the field of industrial robotics but also from micro assembly, addresses several aspects aiming to achieve autonomous programming. There are four fundamental aspects that are essential for the realization of autonomous robot programming.



These are generally applicable not only in the micro assembly context but also across the broader spectrum of industrial robotics. The four key enablers are discussed here. One is called a function module. The foundation of intuitive and autonomous programming is a function or skill representing the functionalities and capabilities of microassembly systems. This comprises robots as well as sensor function parameters that parameterize themselves using a self-learning algorithm.

Second is a holistic simulation, so it is mainly meant to enable offline programming and self-learning operations. A simulation of the whole assembly is necessary, including the robot, robotic peripherals, sensor systems, and the components to be assembled, and the calibration methods used to reduce the gap between reality and simulation, ensuring a seamless transfer. This is particularly relevant in the case of a microassembly, as even a small deviation can have a major impact on the quality of the assembly. Now, let us discuss the data management. It is mainly meant to facilitate the data flow across the different modules and their functionalities.

For this, a centralized database is mandatory. Parked machine and process-related information can thus be saved and accessed conveniently. So, the data management module also includes functionalities for monitoring and visualization of information. Finally, the database serves as an interface for human or software-related inputs and outputs to the framework. Now we also have the autonomous process manager. The process manager is needed to process the information of a given task and to initiate representative data that flows between the different modules.

So, in its form, it will represent the artificial intelligence of the system, i.e., the process, the input, and the output data. It extracts the relevant information and forwards it to the different modules accordingly. It manages the process knowledge and the process sequence according to the requirements. These are some of the frameworks that are applicable to the self-assembly micro-robot perspective. So this is a kind of larger picture and the larger framework that is discussed in a research paper. It can provide a roadmap for the direction in which programming needs to evolve. These are the references that are used for this module on microsystems for micro robotic systems. The next microsystem for micro robotics will be focused on integration, which we will be discussing in the upcoming class.