Development of a novel SEM microgripper

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Abstract. Although there are a number of different microgrippers that have been produced for use in SEM, most of these are made using expensive and time consuming microfabrication techniques such as lithography. In this work a novel type of microgripper has been developed that avoids lithography. Instead, the end-effecters of the gripper are made from a single piece of tungsten wire which is electrochemically thinned and then cut in two with a focused ion beam. Alignment of the two end-effecters is not an issue since they both come from the same wire, so the whole gripper is straightforward and quick to produce and it is possible to shape the end-effecters as desired. Independent electrical connections to each of the end-effecters allow them to be grounded to prevent charging in the SEM beam and give the option of applying a voltage across an object that is picked up. Furthermore, unlike lithographically produced grippers, if the end-effecters become too dirty or damaged it is possible to mount a new piece of tungsten wire and form new end-effecters without having to throw away the whole system. Actuation of the gripper is accomplished using a trimorph bender actuator giving very good resolution (typically ~170nm/V) and a maximum possible span range of over 20μm. The gripper has been successfully demonstrated in picking up and placing copper microspheres in-situ in the SEM.

1. Introduction

With the ongoing interest in the properties of micro- and nano-objects, and the manipulation of these objects into working devices, in-situ scanning electron microscope (SEM) nanomanipulation tools have become increasingly important. Of the nanomanipulation tools in use, the most common is the nanomanipulator fitted with a sharp electrochemically etched tip (used, for example, in [1]). This tool is fine in most cases but can struggle when the micro- or nano-object being manipulated is heavy or has large van der Waals forces between itself and the substrate (e.g. carbon nanotubes lying on a substrate). In situations such as this, electron beam deposition of carbon or another material over the contact between the object and tip can improve the strength of the bond allowing manipulation [1], but this can also contaminate the object.

To allow micro and nano-objects to be manipulated more readily without electron beam deposition, even when large van der Waals forces to the substrate are involved, micro/nanogrippers can be used. Grippers allow larger, opposing forces to be applied to micro and nano-objects making pick-up easier. A variety of different grippers have been manufactured (though not all for use in the SEM) out of...
materials such as gold [2], stainless steel [3], Ni [4,5], NiTi [3], SU-8 polymer [6,7] and even carbon nanotubes [8] but the majority have been made out of predominately silicon and silicon compounds using standard silicon microfabrication techniques such as lithography (e.g. [9-12]) Even some of those that are not made of silicon make use of silicon microfabrication techniques or similar procedures (e.g. [2,6,7]). While lithography techniques have the advantage that they form part of a batch process, the equipment, especially for x-ray and electron beam lithography used for the smallest features, is expensive [5] and not available to everyone. Moreover, the process can be complex [5] and time consuming, and if the gripper end-effecters become dirty or damaged in any way, the complete gripper system must be replaced.

Opening and closing of the manufactured grippers in the literature is generally achieved using electrothermal (e.g. [2,6,12]) electrostatic (e.g. [8,11]) or piezoelectric (e.g. [4,5,9,10]) actuation, though actuation has also been achieved by other means such as voice coil motors [3]. Electrothermal and electrostatic actuators are often used due to the ease with which they can be integrated within a batch process. However, the thermal and potential gradients they create during operation can be problematic for the object being picked up. Even if these gradients are not a problem, electrothermal and electrostatic actuators have a limited movement range and blocking force compared to piezoelectric actuators [3].

In this paper a novel microgripper is presented for use with a SEM nanomanipulator which is made from tungsten wire using electrochemical and focused ion beam (FIB) techniques. Using this method avoids lithography and makes the manufacturing process simple. The end-effecters are also easy to replace if they become dirty or damaged. Actuation of the presented gripper is accomplished using a trimorph piezo bender actuator (Argillon 427.0086.14A). Using a bender actuator simplifies construction, gives a large range of movement with high resolution and avoids unwanted thermal and electrical gradients.

2. Manufacturing the microgripper

The design of the microgripper in this work is relatively flexible and can be modified depending on the specific application. One thing that can be modified is the length of the trimorph bender actuator. Making the actuator shorter decreases the distance of movement of the gripper for a given voltage applied (increases the resolution) but reduces the maximum opening range as a result. The gripper manufactured in this work is constructed with the bender actuator ceramic cut to a length of 12.5mm. The width and thickness of the bender actuator are 1.5mm and 0.8mm respectively.

The gripper is constructed so that the bender actuator supports one of the tungsten end-effecters while a 12mm×1.5mm×1mm fixed stainless steel arm mounted parallel to the bender actuator supports the other end-effector. Connections to the bender actuator terminals are made with PTFE coated 0.125mm silver wires.

The end-effecters for the gripper are made from 0.2mm diameter tungsten wire that is cut to a length of approximately 8mm. The key to the design of the gripper is that both end-effecters are made from this same piece of wire, which is bent in the middle and, after securing both ends of the wire on the bender actuator and stainless steel support arm, cut with a FIB. Doing this means that, when the end-effecters are formed by cutting the wire, they automatically line up with each other avoiding a painstaking alignment procedure (see figure 1).
In order to reduce milling times in the FIB, the tungsten wire is first electrochemically etched at its central point. The etching is done with 2M NaOH solution using the lamellae method [13]. With this method, a 1cm diameter gold ring is dipped in the etching solution so that an etchant film covers the hole. The tungsten wire is then passed through the hole and positioned so the central point of the wire lines up with the film.

The lamellae etch is performed until the middle section of wire has been thinned to a diameter of <40μm. The wire is then bent at this middle section to give an angle of ~30°. It is glued onto to the gripper body with one side stuck to the bender actuator and one side stuck to the stainless steel arm.

Once the wire is secured in place, electrical connections are made to each side of the wire. These connections allow the 2 arms of the gripper to be grounded, preventing them charging in the SEM beam, and can also be used to apply a voltage across an object picked up between the jaws.

After the etching is completed and the wire is secured, the end of the bent section is cut open in a FIB (Quanta 3D 200) to create the 2 arms which can then be shaped as desired (see figure 1). Shaping is usually performed with the ion beam both perpendicular and parallel to the plane of the bend to produce a microscale gripping surface.

3. Performance Evaluation

Although precise gripper performance is highly dependent on parameters chosen during construction (such as length of bender actuator and width of gap milled in the FIB) a typical gripper has been tested in-situ in the SEM (JEOL 6500F). This was found to have a rate of opening of approximately 170nm/V, becoming fully closed at 35V from an initial gap of 6μm at 0V. The gripper has also been mounted in a Kleindiek MM3A nanomanipulator and used to pick up and place Cu microspheres. Spheres between 1μm and 5μm have all been successfully picked up and placed and figure 2 shows the process for a 2.5μm microsphere.
Figure 2. SEM images of the gripper being used to (a) pick up, (b) transport and (c) put down a 2.5μm Cu microsphere.

4. Conclusion
In this work a novel SEM microgripper has been constructed making use of electrochemical etching and FIB techniques to construct the end-effecters from tungsten wire. Since the end-effecters are both made from the same wire which is secured in place and then cut in two using a FIB, alignment of the end-effecters is not an issue making production of the gripper relatively simple. Actuation of the gripper is achieved with a piezo bender actuator which gives good range and resolution, and simplifies construction. The gripper has been successfully demonstrated picking up Cu microspheres.

Acknowledgements
The authors thank the EPSRC for a PhD studentship and funding GR/S85689/01.

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