Thermally driven microgripper as a tool for micro assembly

Katerina Ivanova, a Tzvetan Ivanov, a Ali Badar, a Burkhard E. Volland, a, 1 Ivo W. Rangelow, a Daniela Andrijasevic, b Franz Sümecz, b, c Stephanie Fischer, c Manfred Spitzbart, c Werner Brenner, b and I. Kostic d

a University of Kassel, Institute of Nanostructure Technologies and Analytics (INA), 34109 Kassel, Germany
b Technische Universität Wien, Institut für Sensor- und Aktuatormodule, 1040 Wien, Austria
c Fachhochschule Wiener Neustadt, Fachbereich Mikrosystemtechnik, 2700 Wiener Neustadt, Austria
d Slovak Academy of Sciences, Institute of Informatics, Dubravska cesta 9, SK-845 07 Bratislava, Slovakia

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Abstract

A thermally actuated microgripper was designed and fabricated from single crystal bulk silicon. A gripping width of 5 μm for 5-6 volts driving voltage at a current of 50-60 mA was achieved. The gripper was operated in normal laboratory environment and in vacuum. Gripping experiments were done in a scanning electron microscope. A micron-sized object was gripped, picked up and placed. © 2005 B.E. Volland. All rights reserved

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1. Introduction

Microgrippers are needed for handling and assembly of microparts, for manipulation of biological samples, and for microassembly. In general, microgrippers consist of a pair of tweezers that grab the objects, and an actuator that provides the required force.

Amongst the most popular types of microactuators are shape-memory alloys, electrostatic actuators, piezoelectric, or thermal actuators. Shape-memory actuators operate as on-off actuators, so the control of the gripping force is complicated. Electrostatic actuators generate the force by electrostatic attraction of comb finger electrodes at different electric potential. A drawback of this concept is the required high voltage (up to 100 V) [1], and the sensitivity to dust. Piezoelectric actuators can be designed either as piezoelectric bimorph actuators, or as linear actuators.
employing a lever mechanism. A drawback is the required high voltage of up to 700 V [2].

Thermal actuators rely on thermal expansion of an electrically heated so-called ‘hot arm’ attached to a lever mechanism. They are usually made from SU-8, with thin metal layers serving as conductive layers for the electrical current. They can operate in atmosphere or vacuum, as well as in dusty environment.

The present work uses single crystal silicon as mechanical material, and a so-called ‘two-hot-arms’ design.

2. Design

The microgripper consists of a pair of electrothermal actuators driving a pair of tweezers. The opening of the tweezers is 5 µm wide, while the tweezers are 20 µm long. The electrothermal actuator is based on the bimorph effect. A current is fed through two so-called ‘hot arms’ (275 µm long), heating them due to ohmic resistance, which, as a consequence, expand due to thermal expansion. A so-called cold arm, that is not heated and therefore is not subject to thermal expansion, is attached in parallel to the hot arms. The thermal expansion of the hot arms in connection with the not expanding cold arm creates a torque. It is this torque which that causes the tweezers to close (fig. 1).

In the conventional single hot arm design, the current passes through the hot and cold arm. In order to avoid heating of the cold arm, the cold arm must be wide and short for low resistance, thus interfering with the demands for mechanical elasticity. With the two-hot-arm design, the current passes through the hot arms only, not heating the cold arm.

The base material is single crystal silicon, which is coated by thermally grown silicon oxide, which serves as an insulating layer. The current is fed through a metal layer (Cr/Au) on top of the oxide. Joule heating appears in the metal layer, which heats up the underlying oxide and silicon.

The voltage required for full closing is relatively low (5 V approx.), with a current draw of only a few tens of Milliamperees (50-60 mA). Therefore, the gripper device is can be driven by standard TTL logic chips without the need for additional voltage or power amplifiers.

2.1. Simulations

To optimize the design, the microgripper was simulated with the method of finite elements using the ANSYS software package. First, the resistance and the power dissipation of the design were analytically calculated. Using the dissipated power as input parameter, the temperature distribution inside

<table>
<thead>
<tr>
<th>Material</th>
<th>Young’s modulus [GPa]</th>
<th>Coefficient of thermal expansion [10⁻⁶ K⁻¹]</th>
<th>Thermal conductivity [W m⁻¹ K⁻¹]</th>
<th>Thickness [nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon</td>
<td>160</td>
<td>2.6</td>
<td>150</td>
<td>-</td>
</tr>
<tr>
<td>Gold</td>
<td>78</td>
<td>14.2</td>
<td>320</td>
<td>200</td>
</tr>
<tr>
<td>Chromium</td>
<td>256</td>
<td>6.5</td>
<td>94</td>
<td>100</td>
</tr>
</tbody>
</table>
the device was simulated. As the next step, the thermal expansion and resulting mechanical bending were simulated (fig. 1). The design was optimized with respect to the lengths and widths of the cold and hot arms, to give maximum deflection for a given power. From simulations, a total power of 240 mW is required for a gripping width of 5 µm (for hot arms of 275 µm length).

The mechanical and electrical parameters used are listed in table 1.

3. Fabrication

The devices are made from single crystal silicon (100) wafers. The fabrication sequence is a combination of modified SCREAM and LIRIE process [3-7]. The structures are transferred into an oxide layer (1.2 µm) on top of the wafer by means of contact print lithography and RIE. After resist stripping, the structures are etched (70 µm typical) into the bulk silicon by means of gas chopping DRIE (deep reactive ion etching) [8, 9]. The sidewalls are passivated by means of thin (100 nm) dry oxidation. The passivation at the trench floors is removed by reactive ion sputtering. The movable structures are released by means of isotropic dry etching. Metalization for electrical contacts completes the fabrication sequence. This fabrication process is self-aligned and requires only one lithographic mask.

After separation, the devices were mounted and bonded to ceramic holders. The total dimensions of the device including the holder are approximately 10 x 5 x 1.5 mm³.

4. Experiments

The devices were operated under normal atmosphere, and the gripping motion was observed by an optical microscope (fig. 2). DC voltage was supplied to the gripper, and the voltage and current for fully closed grippers were recorded. Typical values are 4.5-5.5 V at 50-60 mA, in agreement with the calculated power of 240 mW. Destruction due to overheating appears at driving voltages above 7 V. Dynamic measurements were not done, however, the grippers open and close within much less than 1 second.

4.1. Gripping experiments

For gripping experiments, the devices were mounted inside a scanning electron microscope (SEM) on a x-y-z stage. The experimental set-up can be seen in figure 3.

Even in the vacuum of the SEM, the operation parameters were not noticeably altered, indicating that heat transfer through air or convection can be neglected for such devices.

For the gripping experiments, a second passive gripper was used as the target. The active microgripper approaches the target microgripper and grabs a piece of delaminating metal layer. By moving
the stage backwards, the active gripper pulls at the metal film. As a consequence, the bonding between the film and the target microgripper breaks, and the micro part is picked up by the active microgripper.

The taken metal part is then transferred to the tweezers of the passive gripper, and put down. Figure 4 shows the pick-up sequence.

5. Conclusion

An electrothermal microgripper with a ‘two-hot-arm’ design was designed and optimized using finite element simulations, and fabricated. Good agreement between experiments and simulations were found. A driving voltage of 5 V and a current of 50 mA are required to close the gripper. The gripping width is 5 µm.

The fabricated microgrippers were operated both in atmosphere and in vacuum. Gripping, handling and manipulation of microparts were done under vacuum and monitored by a scanning electron microscope.

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References