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Thermomechanical analysis of actuation mechanism of a microgripper fabricated with direct laser writing

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With direct laser writing micro structures can be manufactured by solidifying a photo resist when the laser beam triggers a photochemical reaction in the focal voxel. We have used direct laser writing to fabricate a thermally actuated microgripper, which can move its two cantilever like arms to grip micro-objects. One cantilever consists thereby of two strips with different coefficients of thermal expansion such that both cantilevers bends towards each other for an increasing temperature like a welded bimetal.

This work investigates the impact of each cantilever's geometry on the gripping performance of the micro gripper theoretically. The tip deflection of the gripper is calculated by the analytical model of Timoshenko's theory of elasticity. After fabricaiton of the microgripper, its gripping performance is observed under the microscope while heated by a heating element.

1 Introduction

Manipulating micro-objects is required for a wide range of applications in microrobotics. Direct laser writing permits practicable fabrication of such microgrippers. In direct laser writing, the photo resist used to manufacture the microrobot is activated and solidified by a specific photochemical reaction in the focus of the laser. By changing the process parameters, such as laser power or scanning speed, different laser exposure doses are applied on the photo resist, so that structures with different material properties, such as varying elasticity and thermal expansion, can be created.

In this way we have fabricated a microgripper consisting of two cantilevers connected at one end like a tweezer, as showed in Fig. 1. Each cantilever is made up of two firmly connected strips, for which different exposure doses of the laser are used to realize different thermal expansions. When both cantilevers deflect towards each other, a gripping movement is therefore accomplished. Using Timoshenko's theory of elasticity [1, 2], we analyzed the tip deflection and the gripping force of one cantilever for different geometries.

Gripping movement of the microgripper at a temperature increase from 22°C to 150°C is clearly visible in Fig. 2, so that the desired gripping performance is achievable through the adapted exposure doses in direct laser writing and the resulting different thermal expansions of the structures. A different exposure dose can be realized for example by changing the power scaling factor in direct laser writing.

In our microgripper, while the base and the inner low expansive gray strip are written with a power scaling factor of 100%, the high expansive outer blue strip of the cantilever is written with a power scaling factor of 50%. The whole structure is written by exposing the photo resist with its base stitched to a glass cover slide coated with Al_2O_3 using Dip-in technique, so that the two overhanging cantilever arms are allowed.

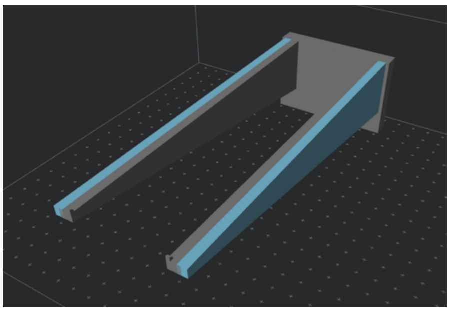

Fig. 1: CAD-model of the microgripper.

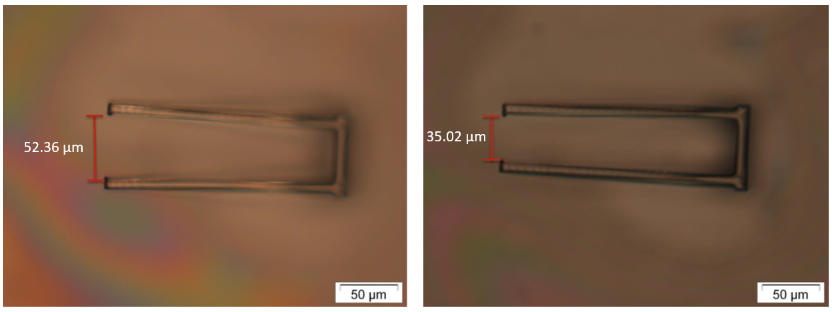

Fig. 2: Fabricated microgripper at 22 °C (left) and 150 °C (right).

2 Analytical method

Fig. 3 shows the sketch of one cantilever of length $l = 200\ \mu m$ consisting of two strips with different coefficients of thermal expansion ($\alpha_2 > \alpha_1$). While the inner low expansive gray strip has a thickness of $t_1 = 7\ \mu m$, the high expansive outer blue

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strip of the cantilever has a thickness of $t_2 = 3\ \mu m$. According to the Timoshenko's theory of elasticity [1, 2], the expression for the curvature is

$$k = \frac{6(1+\frac{t_1}{t_2})^2(\alpha_2-\alpha_1)\Delta T}{(t_1+t_2)[3(1+\frac{t_1}{t_2})^2+(1+\frac{t_1}{t_2}\frac{E_1}{E_2})((\frac{t_1}{t_2})^2+\frac{t_2}{t_1}\frac{E_2}{E_1})]}. \tag{1}$$

In here E_i are the Young's moduli of the photo resist written with different exposure doses and t_i are the thicknesses of each strip, with $i = [1, 2]$. Then the tip deflection of the cantilever for a temperature rise of ΔT results in

$$d = \frac{1}{k} + t_2 - \sqrt{(\frac{1}{k}+t_2)^2 - L^2)}. \tag{2}$$

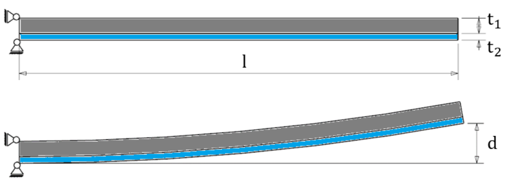

Fig. 3: Sketch of the cantilever.

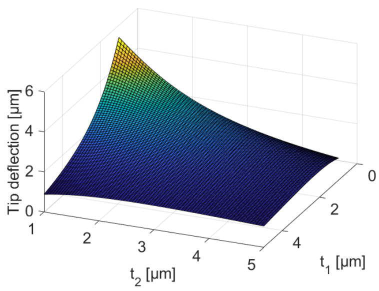

Fig. 4: Dependence of tip deflection on thicknesses of two strips.

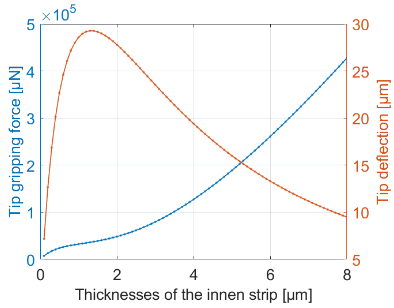

Fig. 5: Balance of tip gripping force and tip deflection.

3 Discussion

In Eq. 1, the coefficients of thermal expansion of both strips are measured in our previous work by use of a controllable heating element [3]. Furthermore, we have used a nanoindentation technique to measure the Young's modulus E_i of the same photo resist, even though in Eq. 1 only the ratio $\frac{E_2}{E_1}$ is needed.

By applying Eq. 2 additionally, a three-dimensional surface plot in Fig. 4 is created, which shows the tip deflection as height above a grid defined by the thicknesses of both strips. In order to obtain a larger tip deflection, both strips need to be applicable possible thinnest. Our provider of the direct laser writing technology, Nanoscribe GmbH, confirms a finest lateral resolution of 0.5 μm and a vertical resolution of 1.5 μm, which thus limits the thickness of the strips.

Relationship between the tip gripping force and the tip deflection, as well as the geometry of each cantilever is also of great interest for a microgripper, since the tip gripping force is generated due to the bending moment of the cantilever, which is caused by thermal expansion and interaction of both strips. The curves of Fig. 5 are drawn from the case that the thickness of the outer strip is taken as $t_2 = 3\ \mu m$, while the thickness of the inner strip varies from 0.1 μm to 8 μm. It is obvious from the curves that the tip gripping force climbs higher with the increase of the thickness of the inner strip, while the tip deflection increases dramatically at first and then falls down. The tip gripping force is hereby given by

$$F = \frac{\Sigma M_i}{l} = \frac{E_1 I_1 + E_2 I_2}{l} k, \tag{3}$$

where M_i are the bending moments on each strip, and $E_i I_i$ are the flexural rigidities of the strips. Therefore we can find optimum thicknesses of both strips for microgripper with desired gripping performance including the tip gripping force as well as the tip deflection.

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