A Tactile Micro Gripper with Piezoelectric Actuator Based on Microsystem Technology

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Abstract
For handling and assembling of small components one sort of micro gripper was developed. It has planar structure and flexure hinges, uses piezoelectric actuation and is fabricated with standard microsystem technology. Micro grippers made of both silicon and glass have been fabricated. Due to its etching angle, gripper made of silicon has no ideal hinge form, which leads to no good mechanical feature, while at glass almost all designs can be fabricated. HF signal was imposed at piezoactutor. A combination of resonant vibration of gripper structure and utilizing self-sensing effect of piezoelectric materials enables micro gripper tactile.

Key words: micro gripper flexible hinge piezoelectric actuator tactile

Introduction
As a rapidly rising field, more and more micro components in different branches have been produced. Thus handling these micro components become necessary. Since the development of parallel-plate electrostatic micro gripper in the University of California [1], some micromachined grippers have been proposed in the literature. They use different actuation types: electrostatic, piezoelectric, suction, SMA and thermal bimorph effect [2,3]. Among them micro gripper with sensitivity of ETH Zürich [4] attracts attention.

In Ilmenau Technical University micro grippers with planar structure made of silicon or photosensitive glass have been developed. It also uses planar piezoeactuator (PZT), which simplifies the assembling work. In this paper one novel idea of combine resonant vibration of gripper structure and self-sensing effect of piezoelectric materials to enable gripper sensitive is presented.

Design and Fabrication
For the fabrication with microsystem technology, a planar structure gains advantage. This type of micro gripper uses piezoelectric actuation. Due to the limited produced displacement of piezoelectric actuator, a four-bar linkage mechanism is used to amplify the displacement (Figure 1). Using compliant mechanism without screws brings much convenience. In this situation flexible hinges (Figure 2) are used, which are also easy to fabricate using lithography and etching technology. The construction for flexure hinges and calculation of those dynamics will not be discussed in details here.

Figure 1: Mechanism and sketch of micro gripper
Figure 2: Flexure hinges in glass and silicon
The compliance of this type of flexure hinge is (see Fig. 2):

\[
\frac{\alpha_z}{M_z} = \frac{9 \cdot \pi \cdot R^{1/2}}{2 \cdot \varepsilon \cdot b \cdot t^{3/2}}
\]

where \( \varepsilon \) is the Young’s modulus. And the stiffness of flexure hinge is the reciprocal of the compliance.

For the fabrication both silicon and glass have been used as standard materials for microsystem technology. The fabrication will be done with standard process: with photo-lithographic method to get its outline, then the wafer will be etched. Due to its etching angle in fabrication, the hinge form of silicon-gripper can not be optimised as at glass wafer in Figure 2 (Figure 3), which affects its mechanical features. Glass, in normal state, has an amorphous structure. It will be etched in all directions as an isotropic material. The UV-exposure changes the inner structure of a photosensitive glass. Through a final thermal treatment a real crystallisation will be generated. After these two processes a so-called anisotropic property will be got and glass can be etched as a real anisotropic material. The fabricating steps are listed in Fig.4. Compared with silicon, photosensitive glass has the advantage of being transparent, high aspect ratio and can generate any outline, which is impossible at silicon because of its etching angle. Thus grippers made of glass were chosen for further usage.

Without extending the gripper finger length, with simply changing construction parameter for flexure hinges different tip-displacement demands can be fulfilled. At another type with the same dimensions as the one shown in Fig.5, tip displacement with \( \pm 2 \times 120\mu m \) at \( \pm 200V \) has been realised, and the maximal gripping force amounts 2mN. According to the theoretical calculation, the gripping force ought to be much higher. Perhaps the flexure hinges have consumed too much mechanical energy.

**Novel Idea Enabling Micro Gripper Sensitive**

In technology it’s difficult to bring a sensing layer down to the glass service. A novel method to bring it sensitivity will be used.

As shown in Figure 6, piezoelectric ceramic is covered with metallic layers on both sides, which serve as contact pad. At one side the metallic layer is cut into two parts. One
part is used for actuating signal, the other for sensing signal. The sensor-part uses the inverse piezoelectric effect. At actuator-part DC-voltage overlapped with AC-signal is imposed. DC-voltage drives the gripper arm and AC-signal with small amplitude is used for sensing. Normally the sensing signal is also unclear opposite noise. Direct measuring brings no satisfying result. Thus HF-vibration helps to find one solution. For one free mechanical structure, for example a micro gripper without object, there are several resonant frequencies due to its elasticity. And at one micro gripper three resonant frequencies are found: 737 Hz, 1605 Hz and 2340 Hz. And at resonant frequencies the phase shift between sensing and actuating signals is about π/2 (Figure 7). At resonant frequency the gripping process will be obvious. After gripping object both amplitude and phase of sensing signal will be greatly changed, which can be used as a criterion for detecting object.

At one resonant frequency (1605Hz), the sensing signals of free gripper and gripper with object are shown in Figure 8. In Figure 8 (a), a little vague figure of gripper can be seen, because the free gripper vibrates at resonance. In Figure 8 (b), about π/2 phase shift between sensing and actuating signal can be observed. Correspondingly, the pictures in (c) (d) present sensing signals after gripping object, and the sensing signal amplitude decreases greatly where the resonance disappeared.

To investigate the gripping process, at beginning point one frequency at not exact resonance was chosen. Naturally when the DC-voltage is imposed on piezoactuator, the resonant frequencies will also depart from the originals because of the generated mechanical stress at flexure hinges. For gripping test one frequency of 750 Hz was chosen, while the original was 737 Hz. And the AC-signal amplitude (p-p) was reduced to 4v. In running course of gripping with object in Fig. 9, at point P1 gripper tip just touched object, the resonant vibration was obstructed, which led to a sudden jump of phase shift up to 180 degree. The gripper tips moved further towards inside till P2. At P2 the sensing signal disappeared and there was only noise signal till P3. From P3 there appeared sensing signal again, with constant phase shift. We can conclude that under this situation there existed one firm gripping and the vibration of gripper tip was transferred through object. Also in running course of phase shift in Fig. 9, the similar conclusion can be got from points A1, A2 and A3.

Figure 7 Dynamic features of free gripper: (a)Sensor signal spectrum; (b) Amplitude of sensing signal and phase shift between sensing and actuating signals around one resonant frequency (1605Hz): DC = 0V, AC-signal-amplitude = 8V

Figure 9 : Both sensing amplitude and phase shift running courses offer gripping information
Figure 8: (a) resonance of gripper tip; (b) actuating signal (above) and sensing signal under resonance; (c) one lens-carrier in gripper; (d) actuating signal (above) and sensing signal after gripping lens-carrier.

Meaningfully the points P1, P2 and P3 coincide well with the points A1, A2 and A3, which means from both sensing amplitude and phase shift running courses information for gripping process can be got.

Discussion and Further Development

The gripping tests were executed on different grippers. The resonant frequencies differ from each other a little. But with this method the gripping information could always be got. For further optimisation electronic circuits for automatically searching resonant frequencies within certain frequency field will be developed. We hope more information could be got through HF-vibrating.

References:
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