Design, Fabrication and Analysis of Microrobotic Insect Wings and Thorax with different materials by MEMS Technology

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Abstract. This paper presents a feasibility step in the development of biomimetic microrobotic insects. Advanced engineering technologies available for applications such as the micro-electro-mechanical system (MEMS) technologies are used. A flapping-wing flying MEMS concept and design inspired from insects is first described. Then different kinds of materials used feasibly for flapping-wing microrobotic insect by MEMS technology, such as SU-8, Titanium alloy and Parylene-C, are discussed. And artificial insect wings and thoraxs with different materials by MEMS Technology are fabricated and analyzed. Finally, summarize the paper and propose future research priorities.

Introduction

Research on flapping-wing microrobots has had great progress in recent years and our teams are currently absorbed in the fabrication of millimeter-scale flapping-wing microrobotic insects. Wood [1] proposed an insect-scale MAV with a 3 cm wingspan and demonstrated the structure could generate sufficient lift to take off using an external power source. Then, at the University of California, Fearing [2] made some attempts to create a micromechanical flying insect with a 2.5 cm wingspan. With the continuous improvement of MEMS technology, polymer and other materials micromachining have enabled the development of complex and reliable microstructures in microsystems. The field of microsystems provides a variety of controlled technologies to produce structures in compliance with insects, with the possibility of mass production, and enables repeatability, size control and weight minimization. Pornsin-Sirirak et al [3] have presented a novel MEMS-based wing technology that they developed using a titanium-alloy metal for the wing frame and Parylene-C for the wing membrane.

In this paper, the feasibility of using MEMS technology to fabricate some components of a millimeter-scale biomimetic microrobotic insect is studied. Based on MEMS technology, MAV can be fabricated to approach insect dimensions, which is the advantage of MEMS technology in Bionics. Different materials applicable in MAV are proposed, fabricated and analyzed based on the structure of Microrobot Flying Insect [1], which is the most successful structure. This is a way for millimeter-scale biomimetic microrobotic insects, and finally, we propose key directions and prospects on future research.

Bionics principles, material selection and structural design

 Biological Principle. In general, wing ‘upstroke’ and ‘downstroke’ is generated by muscles. For insects such as flies and bees, indirect muscles are coupled to a thorax structure, which is tuned to actuate at an optimal quasi-constant flapping frequency [1]. Insect wings are described as largely passive structures, in which muscular forces transmitted by the wing base interact with aerodynamic...
and inertial forces generated by the wing’s motions. The structure of insect wings allows certain beneficial passive deformations while minimizing detrimental bending that would compromise force production.

**Material Selection.** Flapping-wing MAVs have very high demands on the materials which must have the light weight, high tensile strength and so on. Structural materials we selected are commonly used in MEMS, mainly SU-8, Titanium alloy, Parylene-C and so on. SU-8 has become the favorite photoresist for high-aspect-ratio and three-dimensional lithographic patterning due to its excellent coating, planarization and processing properties as well as its mechanical and chemical stability. SU-8 is being increasingly used in MEMS, micro-chip packaging and processing areas [4-6]. University of Lille, France [7] produced a flapping wing electromagnetic microrobot based on SU-8, and it could meet well flight requirements through testing its mechanical properties and vibration. And according to our experiments, there is a good bonding force between SU-8 and Parylene-C, and also harden SU-8 has good strength. Combining these characteristics, we use SU-8 2100 for the veins, the framework and the chest, and use Parylene-C for wing film.

In addition, there is also a very good bonding force between Titanium alloy and Parylene-C, which has been confirmed in MicroBat [8]. But the wing of MicroBat is large and like birds’ wing. Our goal is to produce insect-scale MAV, so the wing and chest structure we needed must be very small. titanium-alloy is light and strong and can be easily tapered to vary the thickness of wingspars. Because it is ductile, it also can be bent to create wing camber to improve performance. In addition, the etching process of titanium-alloy can be conducted at room temperature and yields a reasonable etching rate. To solve isotropic etching, we use double-sided etching and precisely control the etching time.

**Structural Design.** Flapping-wing Microrobot Insect we designed mainly consists of wings, thorax, drives and frame (Fig.1). Use epoxy adhesive to join these parts together. This structure is mainly based on Harvard University's Microrobot Insect [1], but mechanical materials and processing method are all not same. Their process is mainly laser micromachining; the chest has a "sandwich" structure with two layers of carbon fiber prepreg and one layer of polyimide film; wings consist of carbon fiber veins and polyester membrane. Our process is based on MEMS technologies. Because of processing advantages, we can truly making insect-scale Flapping-wing microrobot, and carbon fiber materials can be cut to the highest precision 300µm by laser-machining [1], which limits its miniaturization.

![Fig.1 Design diagram of veins and the whole structure](image1)

![Fig.2 Other shapes of wing](image2)

Also based on wing design principles presented on [8], we also design several other shapes of wing (Fig.2), so that later the aerodynamic characteristics can be compared between different wings in the wind tunnel test.

**MEMS Fabrication details, Patterning results and Analysis**

**SU-8 Thorax Fabrication.** SU-8 2100 process includes spin-coating, soft bake, exposure, post-exposure bake, development, and RIE cleaning (Fig.3). Fixed clean 0.5mm glass substrate (Fig.3a) on the vacuum suction cups and drop photoresist on the substrate, start to spin-coat for 500µm SU-8 (Fig.3b). Use the programmable thermal convection oven for soft bake, and then use precision milling machine to milling surface, then place it in 65℃ oven for 1 hour to remove the knife marks. After UV-LIGA exposure, a post-exposure bake (PEB) on a hotplate was performed to initiate the cross-linking reaction in the exposed areas, which can thus be stabilized against the chemical attack of the developer in the development step. By immersing the substrate in propylene glycol methyl ether acetate (PGMEA) at room temperature, supplemented trillion sound oscillation which can help to fully clean the groove structure, development of the SU-8 layers can be achieved. If SU-8
needs to be hardened, we can hard-bake it and place it in the oven. The conditions: from room temperature to 65°C for 50min, then after 1 hour to 90°C, maintaining for 1 h, and after half an hour to 150°C, maintaining for 15 minutes, then furnace cooling. Finally, the developed substrate was immersed into dilute HF solution for half an hour to remove glass substrate, thus resulting in the lift-off of the final structure (Fig.3d, Fig.4).

**SU-8 and Parylene-C Wing Fabrication.** The first three steps of Wing process are like those shown in Fig.3a–c. Firstly, spin-coat 70µm SU-8 onto 0.5mm glass substrate. Through the lithography, development and other processes (Fig.5a–c), SU-8 wing vein can be fabricated. Then use the PDS 2010 laboratory 2 (parylene deposition system) to deposit 5µm Parylene-C on the SU-8 surface (Fig.5d). If consider the bonding force, you can deposit another layer of film in the opposite again. Finally, immerse it into dilute HF solution, and cut Parylene-C film to form a complete wing (Fig.5e, Fig.6).

**Titanium Alloy and Parylene-C Wing Fabrication.** The fabrication process of titanium-alloy MEMS wings with Parylene-C film is shown in Fig. 7 and described as below. First, a 0.25mm thick titanium-alloy substrate was cleaned in trichloroethylene for 20min (Fig.7a). Later, both sides of the titanium-alloy substrate are coated with AZ photoresist by a spin coater. Exact control of the rotation speed is exercised to get 5µm thick photoresist, serving as a mask layer for subsequent operation (Fig.7b). The both side resists were patterned under UV light (Fig.7c). Then it was hard baked at 120°C for 20min. Next, the substrate is dipped in HF acid to etch uncovered titanium for 25min. Because this was an isotropic etching, the undercut rate was about the same as etching rate. Therefore, undercut must be taken into a consideration when the mask is designed and also aching time is stringently controlled. After the etching process is finished, the wingframes are formed (Fig.7d). Then put the substrate into acetone to strip photoresist from its both sides (Fig.7e, Fig.8). Next, put them on the clean glass substrate and perform Parylene-C deposition (Fig.7f–h). Finally, in order to strengthen the wing membrane, the second layer of Parylene-C was deposited (Fig.7i)
Titanium Alloy Thorax Fabrication. The fabrication process is the same as Fig.7a~e and the Titanium alloy thorax is in Fig.9.

Analysis of these structures. These materials are commonly used in the MEMS field, and through simple process, they can be assembled in the microrobot insect. From the process precision and microminiature of these structures, they can be considered as structure materials to achieve the insect-scale MAV.

Conclusions
To create good flight performance, it need have the theoretical and technological breakthroughs in insect flight, structural optimization, fluid dynamics simulation, and high performance drives. In this paper, key directions and prospects on further research are as follows: 1) Miniaturization and light weight system integration technology. We will study the assemblage technology based on MEMS process to minimize the unnecessary weight. 2) Ansys, Adams and Fluent simulation optimization. Next, we will combine Ansys with Adams to optimize the size and shape, and use Fluent to simulate wing vortexes, getting a good simulation of the structural parameters to better meet the flight characteristics. 3) Drive research and fabrication. Drive capacity, weight and power consumption are all current significant restrictions on microrobotic insects. Now the bimorph drive has gotten a good application [1] and we will further study its drive and fabrication, to drive the microrobot insect for flight as soon as possible.

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