ORIGINAL ARTICLE

Microactuator for Minimally Invasive Surgery*

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ABSTRACT

Background. The processing of nanoparticles facilitates the fabrication of fine functional microactuators as catheter probe tips for minimally invasive surgery. This advantage is particularly essential in microsurgeries, such as surgical procedures for coronary disease, where the operating space is a constraint. It is further noted that in the current procedures, other than the need to develop a smaller catheter, enhancement in efficiency, functions and safety are also required. The objective of the current work was to develop a microactuator, using the nanoprocessing technique with highly functional starting materials, for application in minimally invasive surgeries.

Methods. The fabrication technique, known as electrophoretic deposition (EPD), which is one of the most efficient and effective methods to assemble nanoparticles, was applied to fabricate the functional transducer.

Results. The microactuator fabricated using EPD demonstrated a displacement factor of 1.4, which is the largest ever reported in the literature.

Conclusion. The present work explored a novel technique to fabricate a highly functional microactuating component. This device has widened the scope for many other possible applications in microsurgeries.

Keywords: electrophoretic deposition, microactuators, piezoelectric tubular transducer

INTRODUCTION

Minimally invasive surgery has gained a lot of attention in recent decades as it allows patients a much shorter recovery period after surgical procedures. However, a safer, smaller, and more efficient device is still being sought for performing many of these procedures, such as phacoemulsification surgery and procedures for coronary disease. The current research was aimed at developing a microactuator using a superior functional material to harness the mechanical force to be produced and integrated with ultrasonic energy to help enable minimally invasive surgical procedures to be performed more safely and efficiently. The microactuator driven tip would provide a faster disrupting force with better control in force delivery compared to the traditional ultrasonic or laser techniques, leading to safer surgery with better results.

METHODS

Raw oxide powders of lead oxide, zirconium oxide and titanium oxide were first mixed with the designed stoichiometrical composition and then high energy balled-milled for 24 hours. Considering the volatility of lead oxide during sintering, an additional quantity of lead oxide — 5% — was added to the raw powders. The mixed powders were then calcined at 750^{o}C for 2 hours. Finally, the calcined powders were ground in ethanol by a planetary ball milling machine at a speed of 150rpm for 8 hours. Using a nano-particle sizer (Brookhaven, USA), the ground powders were measured to have a mean particle size of 50nm.

Suspensions were prepared by adding the prepared powders to ethanol and subjecting the mixture to ultrasonic agitation for 6 minutes. The powder concentration in the suspension was 50g/l and the suspension pH was controlled at 4 at room temperature. The suspension was stirred for 3 to 6 hours to make sure of complete dissolution and

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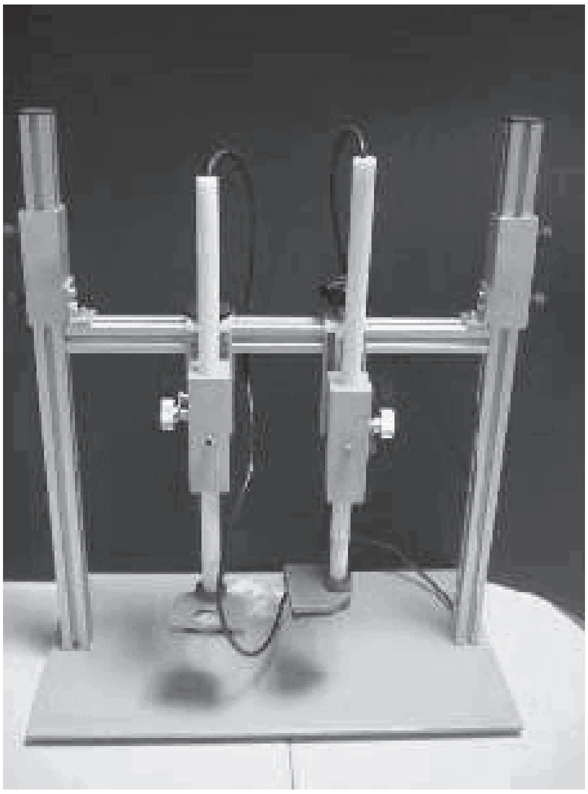


Fig. 1. Electrophoretic deposition apparatus.

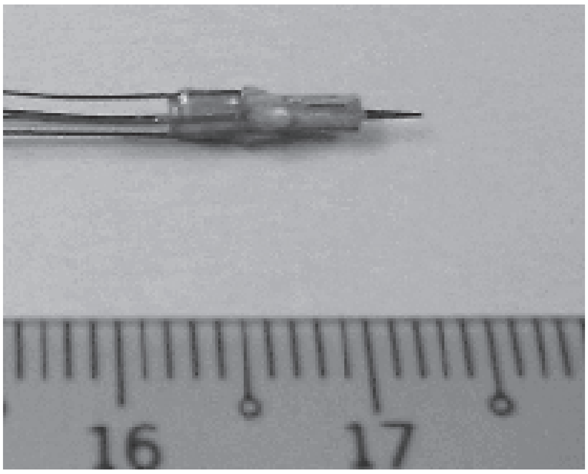


Fig. 2. Piezoelectric microactuator.

Table 1. Performance of the piezo-microactuator.

Mechanical Coupling Factor, k_{31}	0.29
Piezoelectric Constant, d_{31} (μm/V)	-1.40
Speed Rotational (rpm)	510
Frequency Bending (kHz)	105
Frequency Longitudinal (kHz)	210
Torque (mNm)	95

dispersion of the powders in the medium. The electrophorectic deposition system is shown in Figure 1. The electrophoretic cell included a cathode electrode and a stainless-steel anode counter-electrode. The deposition was performed at a constant voltage of 100V for 3 minutes. The deposits were dried for 12 hours and then sintered in a programmable furnace at 1100°C for an hour.

The current sintered tube, of outer diameter 2.4mm, inner diameter 1.8mm and length 8mm, was brush-painted with silver paste to form the electrode before firing at 850°C for 20 minutes. Poling was carried out in silicone oil at 100°C by applying a DC field of 2kV/mm along the radial thickness of the tube for 2 hours. Figure 2 shows the final design of the microactuator.

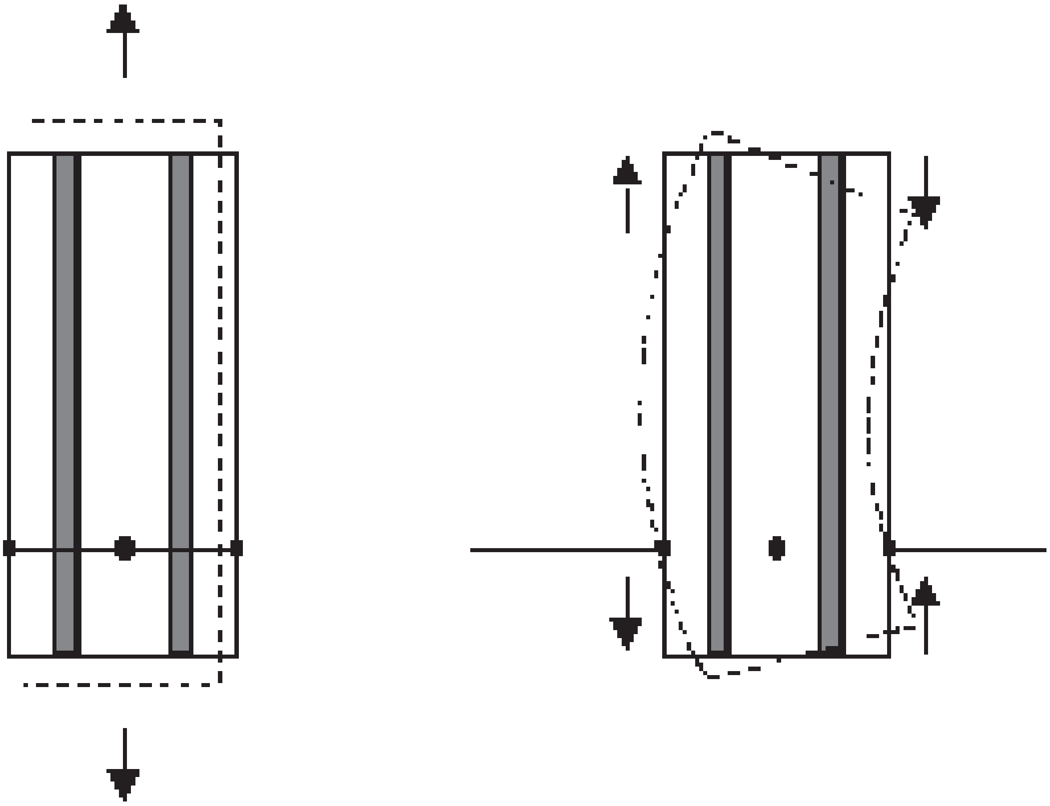
RESULTS

The results of the microactuator performance are summarised in Table 1. The mechanical coupling factor shows the efficiency of a component to convert electrical energy to mechanical energy (Table 1). This study achieved an efficiency of 29%, which is among the highest efficiency that has been reported in the literature. The piezoelectric constant illustrates the amount of displacement of a material under an electric field. The current displacement for both longitudinal and bending was in the order of 10mm. It should be noted that the speed, torque and the actuating frequencies are dependent on each other. In general, high-speed action will couple with high actuating frequency and also result in lower torque, and vice versa.

DISCUSSION

Existing microactuators fall into 2 main types. The first is the servo-mechanical microactuator, which has a problem of poor efficiency when it becomes small in size. This is a major drawback as minimally invasive surgery requires the use of a device which is as small as possible to facilitate both access and recovery. Another problem of the servo-mechanical microactuator is that it produces relatively more heat during operation. Although this heat problem can be reduced by designing the microactuator such that the driven mechanism is at an external position, such arrangements greatly reduce the agility of the catheter or scope-tip.

The second type of microactuator is the piezoelectric type, which is the actuator developed in the present work. The main advantage of piezoelectric



(a) Longitudinal mode.

(b) Bending mode.

Fig. 3. Vibration mode of the tubular transducer.

microactuators is that their efficiency is insensitive to size. As a result, very small piezoelectric microactuators can be produced. It is noted that the most efficient and effective type of piezoelectric microactuator is one that is based on a tubular piezoelectric shape element, where the functional part is a piezo-ceramic tube.[1,2] However, to date, the electrical and mechanical properties of this tube limit the overall performance of the microactuator. It is therefore vital to maximise the mechanical and electrical properties of this functional tube, and at the same time reduce the cost of producing the tube while maintaining its reliability.

This work aimed to develop a superior piezoelectric material to fabricate functional piezo-ceramic tubes for microactuators to be used in minimally invasive surgeries. Nanoprocessing of the starting nano-functional material was employed to facilitate the fabrication of the smallest probe tip possible. An advanced processing technique known as electrophoretic deposition, which is the most efficient and cost-effective technique for the assembly of nano-particles to fabricate micro-components,[3] was applied to fabricate the functional transducer in this work.

The tubular transducer is an elegant design using the piezoelectric deformation and vibration. It is a piezoelectric tube poled in the radial direction and coated with electrodes both on the inside and outside surfaces. When a voltage is applied between the electrodes, the materials in between deform depending on the polarity of the field. This can result in the tube either stretching or contracting in a lengthwise direction (Fig. 3a), or bending perpendicularly to its axis (Fig. 3b). With appropriate design, different actuations, such as rubbing and drilling, can be employed. When the actuation applied reaches ultrasonic frequencies, ultrasonic energy can also be generated. The ceramic material used to fabricate the transducer was a hard material, with a low sintering temperature and suitable for use as the functional material for the microactuator.

CONCLUSION

A small, functional piezoelectric tubular transducer with the desired properties was fabricated using a nanoprocessing technique known as electrophoretic deposition. The device may possess good potential and performance for application in microsurgeries.

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