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Design and fabrication of a PET/PTFE-based piezoelectric squeeze mode drop-on-demand inkjet printhead with interchangeable nozzle

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ABSTRACT

A PET/PTFE-based piezoelectric squeeze mode drop-on-demand inkjet printhead with interchangeable nozzles is designed and fabricated. The printhead chamber is comprised of PET (polyethylene terephthalate) tubing or PTFE (polytetrafluoroethylene, or Teflon) tubing, which of a much softer material, than the conventionally used glass tubing. Applying the same electrical voltage, PET/PTFE-based printhead will generate a larger volume change in the material to be dispensed. The novel printhead fabricated herein has successfully dispensed liquids with viscosities up to 100 cps, as compared to 20 cps for the commercial printheads. Furthermore, PTFE-based printhead provides excellent anti-corrosive property when strongly corrosive inks are involved. The interchangeable nozzle design enables the same printhead to be fitted with nozzles of different orifice size, thus a clogged nozzle can be easily removed for cleaning or replacement. The characteristics of this novel printhead are also studied by dispensing glycerin–water solutions.

1. Introduction

Due to its advantages in automation, low cost, non-contact and ease of material handling, the application of drop-on-demand (DOD) inkjet printing technology has been expanded from conventional graphic printing to new areas, such as fabrication of integrated circuits (ICs) [1,2], LED [3], rapid prototyping (RP) [4], MEMS, cell printing [5–7] and drug delivery [8]. Accordingly, the dispensed liquids have been expanded from the conventional pigmented ink (or standard dye-based ink) to polymers [9–12], gels, cell ink or other materials which often have higher viscosities or even contain large particles or cells.

Consequently, the traditional inkjet printer designed for graphic printing is unable to fulfill the new challenges, one of which is to dispense fluids of very high viscosities. For most of the commercial inkjet printheads supplied by companies like Microdrop, Microfab, Dimatix and XAAR, only liquids with viscosities lower than 20 cps [12] can be consistently dispensed. Fluids with even higher viscosities have to be diluted before printing or warmed up during the printing, which will adversely affect the properties of the liquids.

Another challenge is raised by nozzle clogging. Fluids containing particles, or cells, can easily block the nozzle orifice, resulting in time-consuming nozzle cleaning or even damage of the entire conventional printhead. To solve the problem, the easiest way is to use a nozzle with a bigger orifice, as bigger orifices are less likely to clog. However, this is often not desirable in inkjet printing as bigger nozzles result in bigger droplets and lower printing resolution. In [13], Chen and Basaran reported that by judiciously controlling the piezoelectric parameters governing the flow within the nozzle and thereby the drop formation, droplets with diameters less than 40% of the orifice diameter could be produced. A similar study was carried out by Goghari and Chandra [14]. These studies reveal a possible way to solve this nozzle clogging problem without sacrificing printing resolution. However, their methods only work over a limited range of Ohnesorge numbers.

The poor printability and nozzle clogging may result in unreliable or failed dispensing when using the traditional inkjet printhead design for complex liquids.

In this paper, we will present an in-house-developed PET/PTFE-based piezoelectric squeeze mode inkjet printhead with an interchangeable nozzle design. PET (polyethylene terephthalate) tubing, comprising of a much softer material, is used as the printhead chamber to substitute for the conventionally used glass tubing [15]. Liquids with viscosities of up to 100 cps have been successfully dispensed by this novel printhead. When strongly corrosive inks are involved, Teflon tubing is served as the printhead chamber. The interchangeable nozzle design allows one to easily clean

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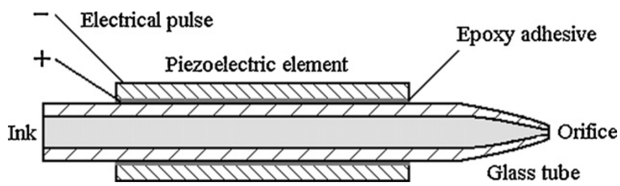

Fig. 1. Schematic showing the construction of a traditional piezoelectric squeeze mode printhead.

or change the clogged or damaged nozzle, avoiding the destruction of the whole printhead assembly.

2. Printhead fabrication

Fig. 1 schematically shows the construction of a traditional piezoelectric squeeze mode printhead. By using epoxy adhesive, a piezoelectric element is tightly attached onto a glass tube which with an orifice at one end. When an electrical pulse is applied, the piezoelectric element will contract inward, squeezing the glass tube as well as the liquid inside. In order to eject a droplet from the orifice, the volume change within the piezoelectric transducer, due to the electrical pulse, must exceeds the volume of liquid to be ejected. Furthermore, the volume change must be sufficient to develop enough pressure inside the liquid to overcome the surface tension at the orifice. The fractional volume change due to the piezoelectric effect is approximately:

$$\frac{\Delta V}{V} = -3d_{31}\frac{U}{t} \quad (1)$$

where d_{31} is the piezoelectric strain constant, U is the applied voltage and t is the thickness of the piezoelectric tube [16]. The negative sign indicates contraction when the applied pulse has the same polarity as the original polarizing voltage for the piezoelectric element. Eq. (1) shows that the printability of a printhead is mainly depended on the piezoelectric strain constant and the geometry of the piezoelectric transducer. In this study, we focus on how to improve the printability of piezoelectric squeeze printheads without pursuing high piezoelectric strain constant. All the piezoceramic tubes (PZT-5H, from Boston Piezo-Optics Inc.) have the same piezoelectric strain constant d_{31}, approximately -275×10^{-12} m/V, at 25 °C.

The basic idea is to reduce the energy loss during the deformation of the liquid chamber, by replacing the traditionally used glass tube with PET or Teflon tube. Accordingly, the printhead is divided into two parts: a printhead chamber and an interchangeable nozzle attachment fitted tightly to the chamber by screw threading. These will now be described in turn.

2.1. Printhead chamber

The design of the printhead chamber is illustrated in Fig. 2a. The PET heat-shrink tubing has a relative low shrinking temperature ranges from 85 °C to 190 °C. Thus a hair drier is recommended to be the heat source, rather than a burner which could burn up the tubing if overheated. To get a uniform shrunken tubing with a desired diameter, a steel tube with 4.9 mm OD is inserted into the PET tubing during the heating process, as a mould. The PET tube with 6.0 mm OD and 0.1 mm wall thickness (230400CHGS, from Advanced Polymers, Inc.) is evenly heated, shrinking it to a tubing with approximately 5.2 mm OD, so that it can fit exactly inside the piezoceramic tube. This shrunken PET tubing is used as the inner wall for the printhead chamber, which directly contacts with the liquid to be dispensed. By using electrical conductive epoxy (CW2400, from ITW Chemtronics Inc.), the shrunken PET tubing is glued to the inner wall of the piezoceramic tube (PZT-5H, from Boston Piezo-Optics Inc.) with 6.35 mm OD, 0.5 mm wall thickness and 25.4 mm in length.

Teflon tubing serves as the printhead chamber when strongly corrosive inks are involved, due to its perfect anti-corrosive property; however, it is such a non-stick material to be directly bonded to the inner surface of the piezoceramic tube. Fortunately, sodium-based chemical etchant can be used to etch the surfaces of the Teflon material, to make it bondable to another material. In this study, the PrimeEtch® Plus solution, provided by Plastomer Technologies, an EnPro Industries company, is used as the etchant. Teflon tubing (from Zeus, Inc.) with 5.22 mm OD and 0.25 mm wall thickness is dipped into the etchant for 5 min. The etching takes place to a depth of a few hundred angstroms and modifies only the surface composition of the Teflon tubing, leaving other properties of the tubing unaffected, even the dimensions. The etched Teflon tube is then rinsed in alcohol for 2 min, dried, and glued to the inner wall of the piezoceramic tube by using electrical conductive epoxy

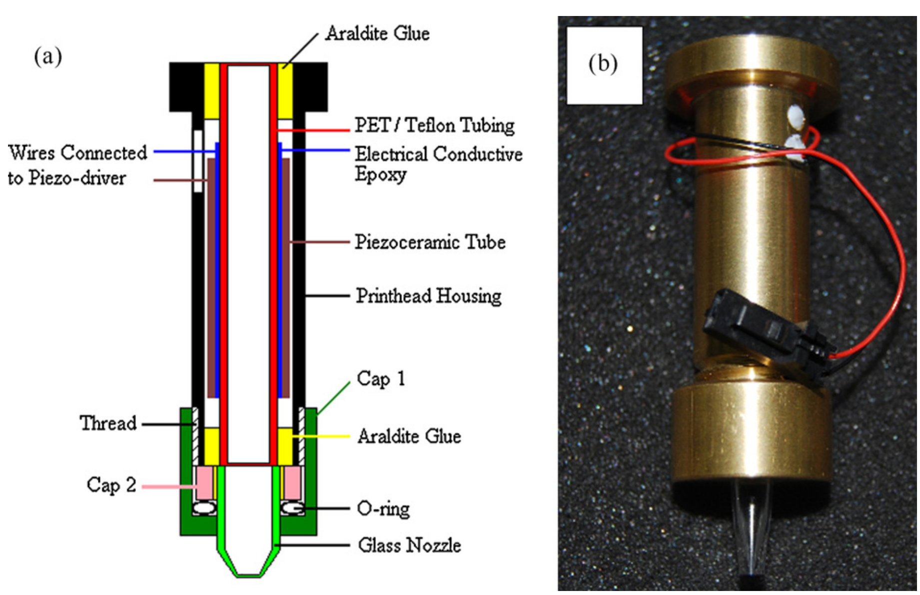

Fig. 2. The novel printhead: (a) schematic showing of the design (out of proportion). (b) A self-fabricated printhead following the novel design.