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A single-step process for making nanofluidic channels using electron beam lithography

J.L. Pearson *, D.R.S. Cumming

Department of Electronics and Electrical Engineering, University of Glasgow, Glasgow G12 8LT, UK

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Abstract

The science of micro- and nano-fluidics has attracted much interest recently. Parallel to this has been the evolution of applications such as the laboratory-on-a-chip, and recently, the possibility of single molecule detection. In order to realise such applications new fabrication methods are required.

In this work, we demonstrate a simple, single-step process using electron-beam lithography to write parallel ribs of cross-linked UV-3 resist. The resist is spun on to a SiO_2 layer on a silicon substrate. If the resist thickness, electron dose, rib width and gap width all lie within a limited range, then the ribs collapse or fold towards each other making a sealed contact at the apex. This action depends on the exploitation of the forces of surface tension and capillarity during the final drying process.

Keywords: Nano-fluidics; Electron beam lithography; Capillarity

1. Introduction

Micro-fluidics for applications such as laboratory-on-a-chip has now become a well-established technology for genetic sequencing and drug discovery [1]. More recently there has been a growing interest in nano-fluidics since this technology offers the possibility for single molecule detection and other sophisticated applications such as the fabrication of synthetic vascular networks for tissue engineering and repair. A variety of techniques have been investigated including the use of lipid membranes in liquid suspensions [2], focused ion beam milling on silicon nitride membranes [3] and patterning of polymer layers using electron beam lithography [4]. Of the latter, which was the only one that enabled the direct-write of multiple channels on a planar substrate, the fabrication technique was relatively complicated and required the use of a sacrificial layer that was removed using an access port etched into the back-side of the specimen.

* Corresponding author.
E-mail address: j.pearson@elec.gla.ac.uk (J.L. Pearson).

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We have developed a process that enables the fabrication of nanoscale enclosed channels, using only a single layer of lithography on a conventional wafer. It is based on the exploitation of the naturally occurring forces of capillarity to cause two adjacent polymeric ribs to collapse in upon one-another to form a seal at the apex. In this paper we will present the details of the fabrication methods used in Section 2, in Sections 3 and 4 we will discuss the influence of surface tension, capillarity and drying method, and in Sections 5 and 6 we will present the discussion and conclusions.

2. Experimental procedure and fabrication

In order to investigate the formation of the enclosed channels, a systematic series of experiments was carried out. Central to this aim was the formation of adjacent pairs of "ribs" or "walls" of cross-linked UV-3 resist, defined by heavy electron beam exposure. The typical exposure pattern used is shown in Fig. 1(a). UV-3 is a commercially available DUV resist based on a copolymer of hydroxystyrene and *t*-butylacrylate. It is a chemically amplified photoresist that is also sensitive to electron exposure. It is relatively sensitive to electron exposure and the normal dose required ($\sim$30 μC cm^{-2} at 50 kV) is approximately an order-of-magnitude less than that required for other commonly used positive-tone electron-beam resists such as PMMA. In this work, we deliberately over expose the UV-3 so that it cross-links and behaves as a negative-tone resist. Under the correct drying conditions the pairs of ribs that we write into cross-linked UV-3 bend toward each other to join at their apices and form a single enclosed channel or tube.

The factors influencing the collapsing effect that were investigated are shown in Fig. 1(b). These were: varying the rib width (x) from 60 to

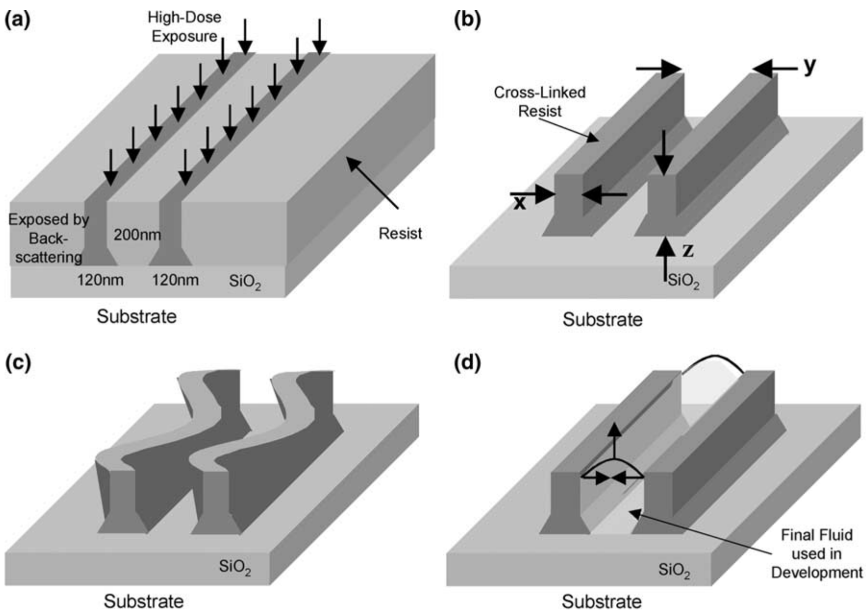

Fig. 1. The schematic fabrication sequence prior to drying. (a) Rib-pair structures were created by heavily exposing the UV-3 resist at 4000 μC cm^{-2}. Forward scattering created a cross-linked plinth at the base, and that back-scattered electrons exposed some of the surrounding resist. (b) The rib pair expected after development with dimensions shown. (c) The rib pair generally obtained if the resist was sufficiently rigid. Note the distinct ripple at the top of the ribs. (d) An illustration of the net cohesive and adhesive forces typically existing prior to drying in air. Note that the component forces act inwards and upwards conferring force on the ribs so that under the correct conditions a tube may form.