Fabrication of aluminum electrodes by water and light

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Abstract—Rapid fabrication of 1–5-μm-wide aluminum electrodes by a flexible, inexpensive and high-resolution process is demonstrated. The electrodes are produced by scanning a cw focused laser beam of 488 nm wavelength over an aluminum thin film of 50–100 nm thickness immersed in pure water and removing the metal by local low-power laser-thermal corrosion. The process is performed on a set-up operating in common laboratory conditions. The aluminum patterning requires only several milliwatts of laser light, which allows the use of inexpensive light sources and makes it especially suitable for structuring metal films on heat-sensitive materials such as polymers. Interdigitated microelectrode arrays on poly(dimethylsiloxane) and SU-8 resist are fabricated without damaging the substrate. By taking advantage of the intrinsic 3D processing capability of laser machining and thick film techniques developed for polymer-based microsystems, multilayered electrode structures in SU-8 are produced. Interconnections between the different electrode layers are realized via holes drilled through the intermediate polymer by laser ablation in air and subsequent metallization. The rapid prototyping of an asymmetric electrode array for electrohydrodynamic pumping within 4 h is demonstrated. Successful testing of the device by pumping of water provided evidence of correct electrode operation.

Keywords: Laser processing; aluminum; thin film; corrosion; rapid prototyping; sensors; microfluidics.

1. INTRODUCTION

The inexpensive patterning of metallic thin films is of great importance for prototyping and developing micro-electronic and -mechanical devices employed in various fields such as micro-robotics [1], optical display technology [2], chemical sensing [3] and biotechnology [4]. The metal electrodes used for such microsystems are commonly fabricated by an elaborated multi-step lift-off process, which requires clean-room facilities and involves costly lithographic masks or electron beam de-
vices and aggressive chemicals [5]. Lithographic masks are commercially available; however, their production may introduce unnecessary delays in the device development process. In order to accelerate this process and to reduce cost and enhance flexibility, structuring schemes such as rapid photolithography [6], xerographic toner masking [7] and ink-jet printing [8] were developed. These processes are especially suitable for microsystems of less demanding feature sizes than those needed in microelectronics. The resolution of these lithography techniques is limited to several tens of μm. Laser machining [9], in contrast, has proven to be a simple and flexible tool for patterning in the micrometer range. Recently, we suggested a one-step lithography process for aluminum thin films which is based on low-power laser-thermal corrosion in pure water yielding features sizing in the range of 270 nm to several micrometers in width [10, 11]. The water-immersed aluminum film is patterned by a focused laser beam, which is scanned over the metal surface. The aluminum is locally heated by light absorption, which inhibits passivation by the native oxide and induces corrosion, removing the metal from the substrate. During laser processing, the temperature of the aluminum film is increased close to the boiling point of water, requiring a laser power of only several milliwatts. At 100°C the water evaporates, forming steam bubbles that interrupt the supply of reactants to the metal surface and abruptly terminate the corrosion process. The process thus imposes an intrinsic limit on the laser irradiation power [10]. This power is considerably less than is needed for laser-assisted metal ablation, where the material is evaporated. The low-power property of this lithography method allows the use of inexpensive light sources. Moreover, it makes the process especially suitable for structuring aluminum films on heat-sensitive materials such as polymers, addressing the increasing demand for ‘soft’ structuring schemes to fabricate plastic microsystems. The process works in pure water without any addition of acids or lyes that may cause chemical damage to the substrates or harm the environment. Since the substrate is submersed in water during structuring the susceptibility to pollution of the surface by dust particles is considerably reduced in comparison to lithography methods operating in air. The process, therefore, offers great potential for high-yield production at high spatial resolution outside the cleanroom environment. Here, we demonstrate successful fabrication of micrometer-sized aluminum electrodes on glass and on polymers such as poly(dimethylsiloxane) (PDMS) and SU-8, a near-ultraviolet photoresist [12], without damaging the substrate. Furthermore, rapid prototyping of electrode arrays for electrohydrodynamic pumps with feature sizes in the range of some micrometers within several hours is shown, taking advantage of the flexibility of the simple microlithography process.

2. PRINCIPLE

Aluminum forms a thin passivation layer of hydargillite (Al₂O₃·3H₂O) when exposed to neutral water of pH 7 at room temperature [13]. It is oxidized in an