Nanofluidic Devices in Glass with Poly-Si Electrodes

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***Abstract*—In this paper we propose a novel fluidic device fabricated in glass (by glass-to-glass anodic bonding) with poly-silicon electrodes. We have characterized the resistance of the poly-silicon electrodes and we have successfully fabricated different nanofluidic devices to show the feasibility of the proposed fabrication process. We show that with this fabrication process it is possible to fabricate electrodes (with sheet resistance of about 400 Ω/□) in the a:Si layer used as an intermediate layer for the anodic bonding. The resistance of the poly-Si electrodes could be further significantly reduced by adding few fabrication steps in which the top of the poly-silicon electrodes is covered with Al layer.**

Keywords— **micro- and nanochannels; fluidic devices; anodic bonding; glass; poly-Si electrodes**

I. INTRODUCTION

The past years, the micro- and nanofluidic devices are gaining a lot of attention because they allow biochemical analysis to be performed using very small amount of the samples to be investigated. Optical microscopy has been proven to be a reliable and sensitive technique as being used for a large number of quantitative applications. Therefore, glass with its transparency, becomes a very suitable material for the fabrication of the fluidic devices giving the opportunity electrical measurements to be performed in combination with fluorescence microscopy.

The fabricated nanofluidic devices, described in this paper have many advantages: the electrodes are part of the sidewalls of the channel and therefore no leakages should occur due to surface roughness problems (the planarity of the surface of the a:Si and the poly-Si layers is preserved). Furthermore, no noble metals are used in the fabrication process and therefore it is a clean room compatible process. However, proper care has been taken with the glass, which is sodium rich in order to be suitable for the anodic bonding, and therefore the cross contamination of sodium has to be prevented.

II. EXPERIMENTAL

Recently we have developed a technology for manufacturing fluidic devices in the intermediate layer between two anodically bonded glass wafers [1]. We used a Borofloat type glass wafers and as an intermediate layer we used a 33 nm LPCVD a:Si layer deposited on the bottom glass wafer [2,3]. After the intermediate layer is deposited, channels (50-150 nm deep) are etched by reactive ion etching (RIE) in this layer through a photoresist mask. In the next step the glass wafer is bonded anodically to a second (top) glass wafer in order to seal completely the fluidic devices. The top wafer might have pre-machined openings at predefined positions as access holes to the channels. In our case we have 1 mm in diameter ultrasonically machined holes in the top glass wafer. The basic process flow for the fluidic devices without electrodes is shown in Figure 1.

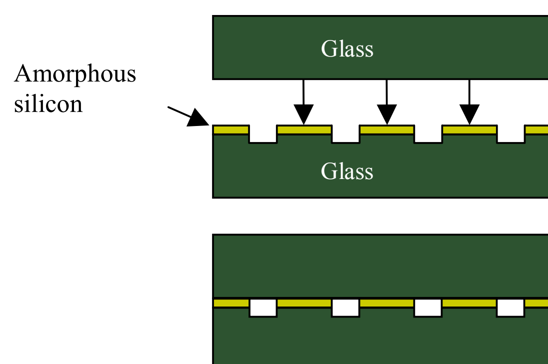

Figure 1 Basic process flow for nanochannels.

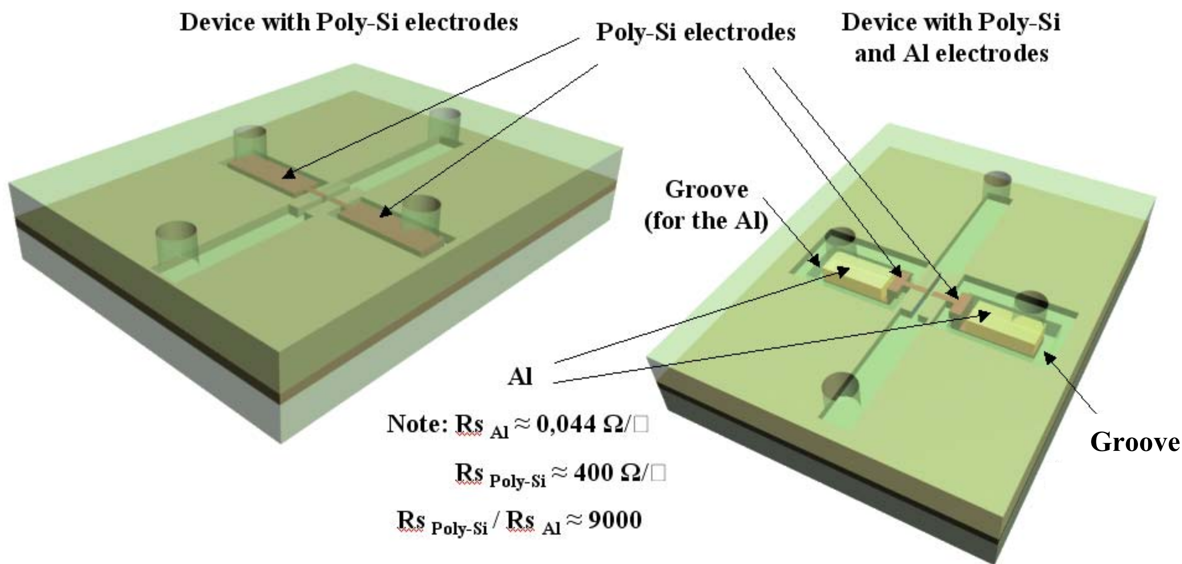

Figure 2 Schematic view of the fluidic chips with poly-Si electrodes and the one with poly-Si electrodes in combination with Al electrodes.

The a:Si layer between the two glass wafers has a very high resistance and therefore it is not conductive. Doping the a:Si layer selectively (through a mask) with As^+ ions will allow reducing significantly its resistance and makes it conductive. To achieve a very low resistance of the doped area, subsequently the a:Si layer has to be annealed in order to activate the dopants. In this manner electrodes with very low resistance can be fabricated. Sketch of the proposed device is shown in Figure 2 (left picture).

In order to measure the sheet resistance of the electrodes we fabricated van der Pauw structures [4] on 3 silicon wafers. On top of the silicon wafers we deposited 1 µm thermal oxide. Afterwards, we deposited 33 nm LPCVD a:Si in the same manner as it was deposited on the glass. The thermal oxide is needed to isolate the silicon wafer from the a:Si layer. We doped all three wafers with As^+ ions with different concentrations: 5e+14 ions/cm^2; 1e+15 ions/cm^2 and 2e+15 ions/cm^2 at 5 keV. To activate the dopants we used a XeCl excimer laser (XMR 7100 system). The wavelength of the excimer laser light is 308 nm and the single irradiated spot was 1 cm x 0,5 cm with a pulse duration of 58 nm. An excimer laser was used instead of a standard furnace annealing due to the low melting temperature of the glass (around 500 ^{o}C). The excimer laser is capable of generating heat mainly in the a:Si layer due to the very high absorption of the deep UV light of the laser. In that manner the a:Si layer is melted and re-crystallized as a polycrystalline silicon layer. The grain size and the growth mechanism of the crystals, which are important for the resistance of this layer, are dependant on the laser energy [5]. Therefore, we performed annealing with different radiation energies starting from 200 mJ/cm^2 up to 350 mJ/cm^2 with a step of 25 mJ/cm^2. By multi-shot irradiation with zero overlay it is possible to anneal the whole surface of the substrate in around 1 minute. After the annealing the whole surface on each wafer was patterned and the poly-Si layer was etched in order to create the van der Pauw structures. Next, a PECVD SiO_2 layer was deposited and patterned with contact windows. To form the contact pads Al/Si (1%) layer was sputtered and subsequently patterned followed by an alloying step in order to form a low-resistance contact between the metal and the polysilicon.

The sheet resistance of the van der Pauw structures was measured by four-point measurement. For each radiation energy we measured up to 32 structures. The lowest average sheet resistance of about 400 Ω/□ was achieved at laser energy of 300 mJ/cm^2 and concentration of the As+ dopants of 2e+15 ions/cm^2. Obviously the higher concentration of the As+ ions was favorable for the lower average sheet resistance of the van der Pauw structures.

AFM measurements were performed before and after the excimer laser annealing (with an irradiation energy of 200 mJ/cm^2). The average roughness before the irradiation was 1,43 nm and 2,1 nm after the irradiation.

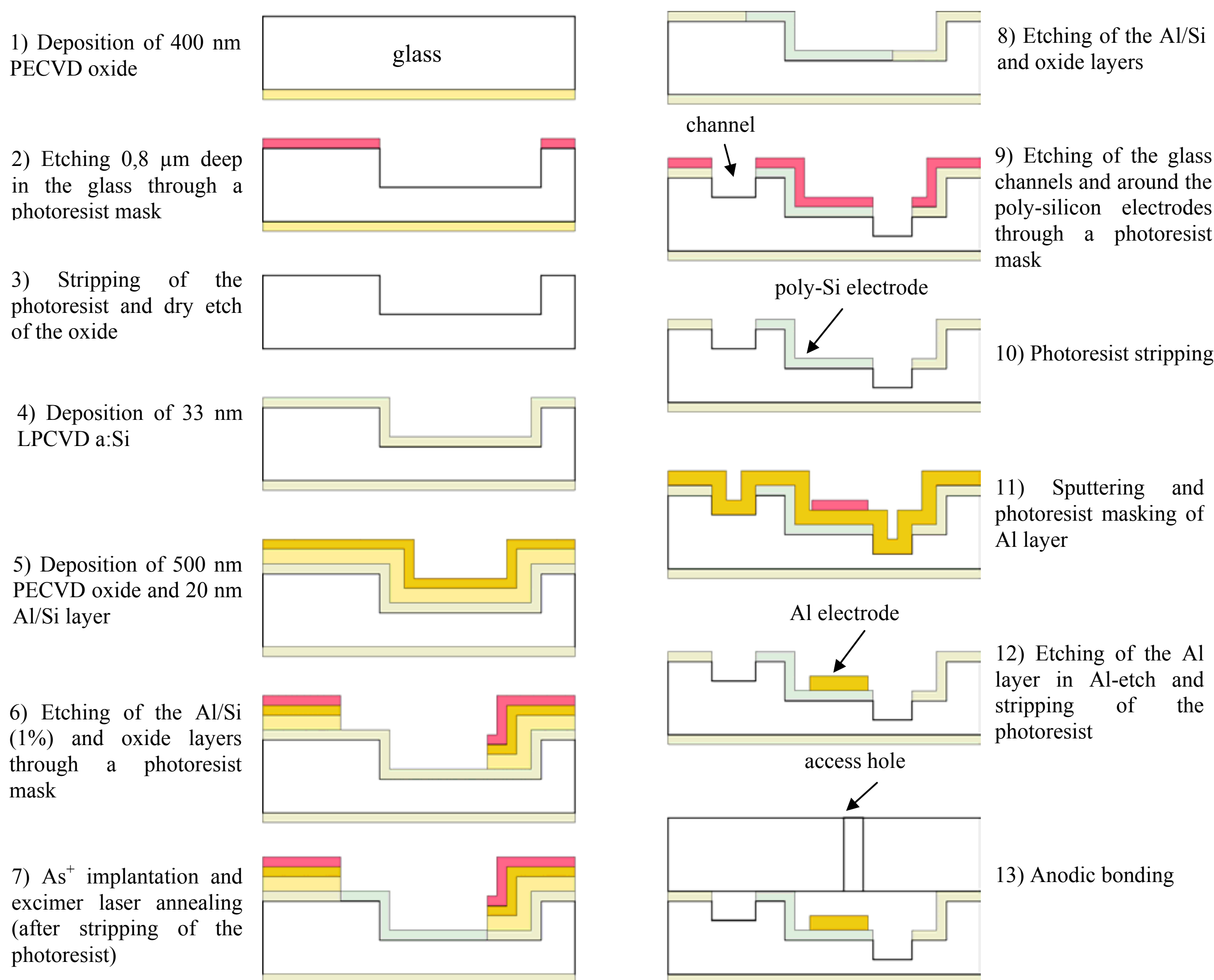

Figure 3 Basic fabrication process of the nanochannels with poly-Si electrodes in combination with metal.

I. FABRICATION PROCESS

The preliminary tests showed that electrodes with very low sheet resistance (of about 400 Ω/□) could be fabricated in the a:Si layer. However, lower resistance of the electrode might be favorable for many applications. The resistance of the electrodes could be significantly reduced if larger part of the electrodes is covered with 0,6 µm Al layer, as shown in Figure 2 (right picture). Since the sheet resistance of the aluminum is around 0,044 Ω/□ the total resistance of the electrodes could be reduced up to approx. 9000 times in this manner. However, to preserve the planarity of the surface a few additional steps are required during the manufacturing of the fluidic devices. The poly-Si electrodes, which are coated with aluminum, have to be located in specially etched grooves so when the aluminum is deposited its surface is below the surface of the a:Si. The basic fabrication flow for the nanochannels with poly-Si electrodes in combination with aluminum is shown in Figure 3. In the first step the glass wafer is protected with 400 nm PECVD oxide on the back side. It is necessary to prevent any contamination of the equipment coming from the sodium ions in glass. In the next step 0,8 µm grooves are etched by RIE (reactive ion etching) through a photoresist mask. These grooves are necessary as later the aluminum will be deposited there over the poly-Si electrodes. In the next step the oxide is striped from the back as it is not anymore required and 33 nm LPCVD a:Si layer is deposited on the wafer. The a:Si layer does not allow the sodium ions to contaminate the equipment, which is being used. In the next step 500 nm PECVD oxide and on the top another 20 nm Al/Si layer are deposited and subsequently both layers are etched in BHF through a photoresist mask defining the location of the electrodes. It is necessary this etching to be

performed shortly before the implantation with As^+ ions as it is important the native oxide to be etched as well. After the implantation the photoresist is stripped and annealing step has to be performed. The aluminum layer is required to reflect the irradiated light from the excimer laser and in that manner to prevent the area from annealing. After the excimer laser annealing is performed the aluminum layer and the oxide are not anymore needed and they are subsequently stripped in BHF. In the next step the fluidic channels are etched by RIE, including also some channels around the poly-Si electrodes which purpose is to reduce the electrical leakages between the electrodes and the undoped a:Si layer. Next an aluminum layer has to be sputtered and patterned through a photoresist mask. After cleaning the wafer for 10 minutes in HNO_3 (100%) in order to clean and make the surface of the wafer hydrophilic, in the last step the glass wafer is anodically bonded to a second glass wafer to seal completely the fluidic devices.

Main advantage of these fluidic devices is that they are transparent thus allowing fluorescence microscopy to be utilized. The poly-Si electrodes have sheet resistance of about 400 Ω/□, which can be additionally reduced by the deposition of an additional aluminum on top. The electrodes are part of the sidewall of the channel and therefore no protection of the electrodes is required. A special etched groove was made in order to minimize the electrical leakage between the a:Si layer and the poly-Si electrodes.

Figure 5 shows two fluidic channels: one is realized with only poly-Si electrodes (left image) and the other one with poly-Si electrodes in combination with aluminum (right image). The realization of the fluidic channels with only poly-Si electrodes is easier as it requires less process step. Furthermore, the electrodes are self-aligned. However, when aluminum layer is applied on top of the poly-Si electrodes the sheet resistance of the electrodes is significantly reduced.

IV. Results and Conclusions

We have fabricated different fluidic devices to test the fabrication technology. One of the fabricated devices with poly-Si electrodes in combination with Al layer is shown in Figure 4. The channels on the picture are 150 nm deep and have different width up to 1,5 mm. The grooves for the buried electrodes are 0,8 μm deep, which is sufficient to bury the 33 nm thick poly-Si electrodes and the 0,6 μm thick aluminum layer on top.

V. Acknowledgements

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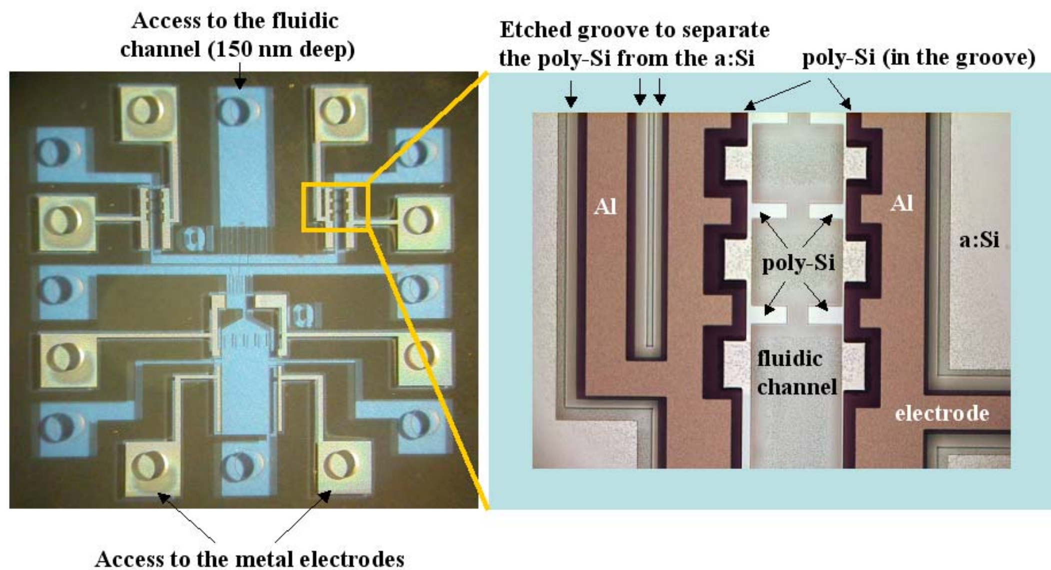

Figure 4 Fabricated device with poly-Si electrodes in combination with Al electrodes.

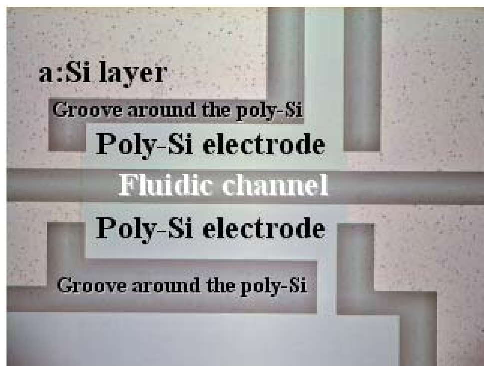

Figure 5 Comparison between a fluidic chip with poly-Si electrodes and another one with poly-Si electrodes in combination with Al.

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