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Annealing of Nanocrystalline Silicon Micro-bridges with Electrical Stress

Gokhan Bakan[1], Adam Cywar[1], Cicek Boztug[1], Mustafa B. Akbulut[1], Helena Silva[1] and Ali Gokirmak[1]

[1]Electrical and Computer Engineering, University of Connecticut, 371 Fairfield Way, Storrs, CT 06269, USA

ABSTRACT

Nanocrystalline silicon (nc-Si) micro-bridges are melted and crystallized through Joule heating by applying high-amplitude short duration voltage pulses. Full crystallization of nc-Si bridges is achieved by adjusting the voltage-pulse amplitude and duration. If the applied pulse cannot deliver enough energy to the bridges, only surface texture modification is observed. On the contrary, if the pulse is not terminated after the entire bridge melts, molten silicon diffuses on to the contact pads and the bridge tapers in the middle. Melting of the bridges can be monitored through current-time (I-t) and voltage-time (V-t) measurements during the electrical stress. Conductance of the bridges is enhanced after the electrical stress.

INTRODUCTION

Thin-film transistors (TFTs) are one of the major components in large-area electronics [1]. Imaging and sensor arrays such as active matrix liquid crystal displays and x-ray imagers use TFTs as switches and in peripheral circuitry [1]. Amorphous silicon (a-Si) is commonly used as TFT material for reliable and cost-effective large-area electronics applications. Although a-Si has very low electron mobility [2], it has the advantage of uniform and low-temperature processing which may also provide the opportunity of using flexible materials like plastics as the substrate [3]. Interest in the studies of the silicon crystallization methods has increased in last several decades due to low processing temperature requirements and demand for high performance TFTs[2, 4]. In this work, crystallization of nanocrystalline silicon (nc-Si) bridges by electrical stress [5] is studied as a silicon crystallization method.

Nc-Si films are deposited on a thermally grown oxide in a low-pressure chemical vapor deposition (LPCVD) system with high-level phosphorous doping (~5×10^{20} cm^{-3}) [6]. Nc-films are patterned as wires with large contact pads using photolithography and reactive ion etching (RIE). Nc-Si wires are released from the underlying oxide using buffered oxide etch to form bridges. As fabricated bridges have lengths ranging from 0.5 to 5 µm and widths in the order of 0.5 µm.

EXPERIMENT and DISCUSSION

Large-amplitude short-duration square voltage pulses are applied across the nc-Si bridges by making contact with large nc-Si pads using tungsten probes. Applied voltage and the corresponding current through the bridges are monitored by a high-speed oscilloscope as shown in Figure 1.

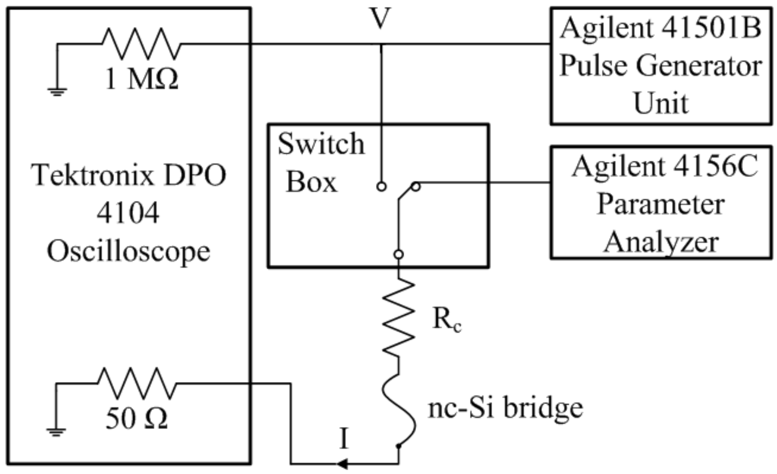

Figure 1. Circuit schematic of the experimental setup, where R_c is the contact-pad resistance. I-V characteristics of the bridges are measured by the parameter analyzer before and after the electrical stress. Switch box switches to pulse generator unit to apply the voltage pulse. Applied voltage pulse amplitude and current through the bridge are acquired by the oscilloscope.

Surface melting and modification (Figure 2b) is observed on the bridges, when the energy delivered by the electrical pulse is not sufficient to melt the entire bridge. Figure 2c shows a melted and crystallized bridge. While the contact pads keep their initial nc-Si structure, the bridge has smooth texture and a lump in the middle. The crystallized bridge is under tensile stress; although as fabricated bridges are relaxed (under compressive stress). The lump in the middle suggests that the solidification process starts from the two ends of the bridge and moves towards the middle. When two fronts meet, excess liquid silicon in the middle is ejected and forms a lump upon solidification. If the electrical stress is not terminated after the melting of the bridge, liquid silicon can diffuse on to the contact pads and the bridge disconnects as shown in Figure 2d. Surface modification in Figure 2b suggests that melting of the bridges starts on the surface.

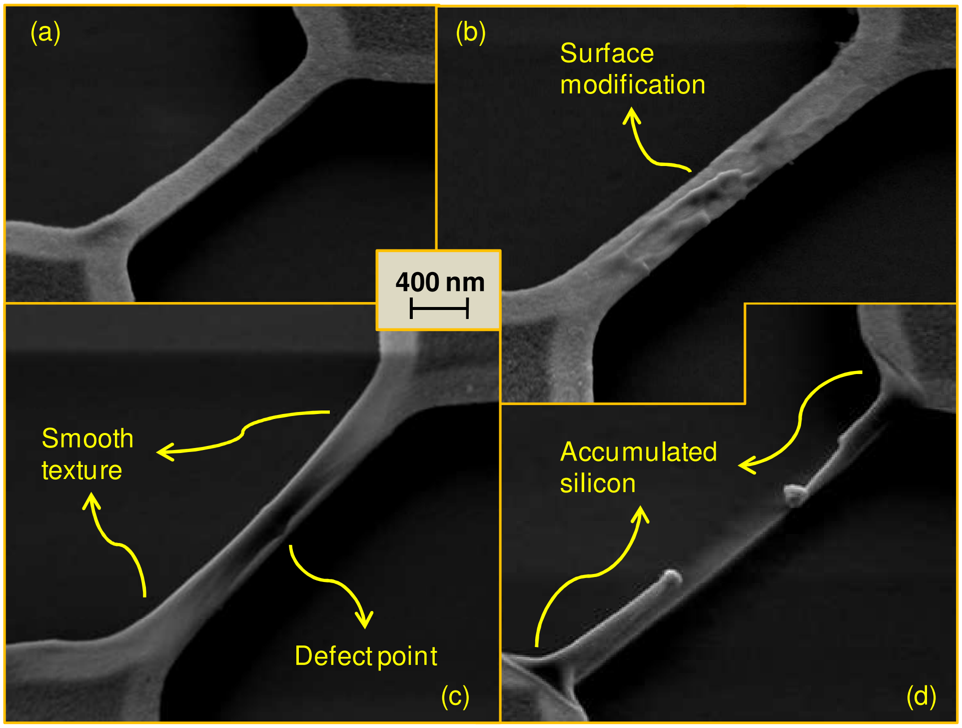

Figure 2. (a) An as fabricated 3.5 µm long nc-Si bridge. The bridge and contact pads have uniform nc-Si texture. (b) A 5 µm long bridge stressed with 30 V, 1 µs pulse. Applied electrical stress melted and modified the surface. (c) A 4 µm long bridge stressed with a 25 V, 1 µs pulse. (d) A 5 µm long bridge stressed with 30 V, 1 µs pulse. The bridge is fully molten and broken.

Melting and re-solidification process can be monitored through the I-t and V-t measurements. In Figure 3, I-t and V-t graphs of the bridges shown in Figure 2b, 2c and 2d are given. In the case of surface modification (Figure 2b), the current increases between the rising and falling edges of the applied pulse without showing any significant jump (Figure 3a). The minimum resistance of the bridge during the stress (15.1 kΩ) is much smaller than its resistance after the stress (76.3 kΩ). Small resistance during the stress can be attributed to the resistivity decrease due to increased temperature and negative temperature coefficient of resistivity [7] of nc-Si, and partial (surface) melting of the bridge. In the case of complete crystallization (Figure 2c), I-t behavior shows a sudden jump (indicated with the dashed line in Figure 3b) during the stress. Gradual increase in the current after the drastic jump suggests that melting of the bridge continues during the entire pulse. If the entire bridge melts before the pulse is terminated, molten silicon diffuses on to the contact pads (Figure 2d) leads to breaking of the bridge for sufficiently long pulses (Figure 3c).

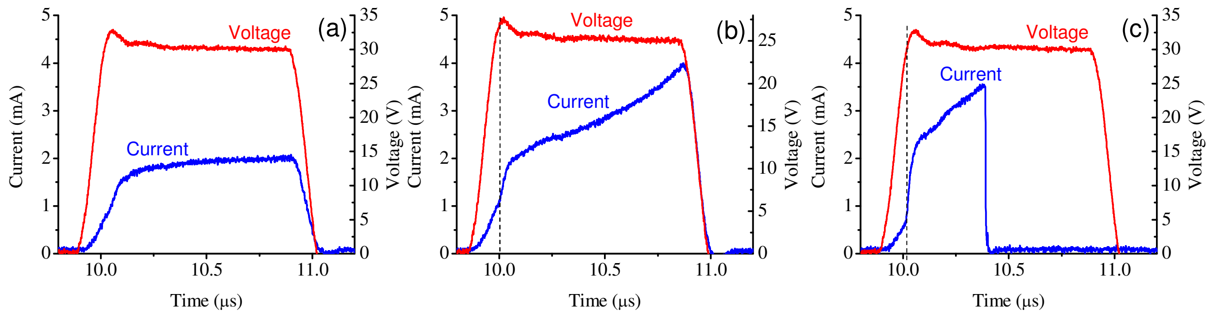

Figure 3. V-t and I-t graphs of the bridges (a) in Figure 2b, (b) in Figure 2c, (c) Figure 2d. Vertical dashed lines in (b) and (c) indicate the time when the current drastically increases.

I-V characteristics and conductance of the crystallized bridge before and after the electrical stress are shown in Figure 4. Conductance versus voltage behavior shows that tungsten probes are making ohmic contact with silicon pads. Conductance of the bridge together with contact pads is enhanced after the stress, although contact pads' surface texture is not modified by the applied pulse.

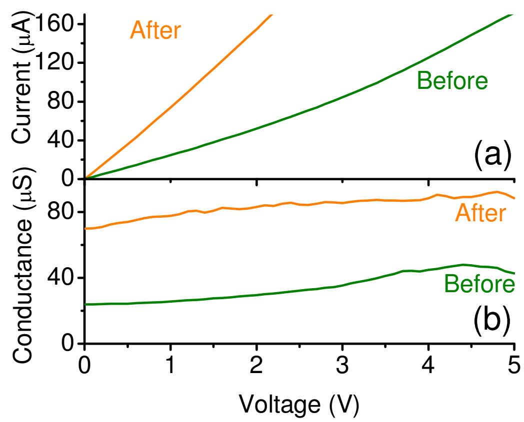

Figure 4. (a) I-V characteristics of the bridge shown in Figure 2b, before and after the electrical stress. (b) Conductance of the bridge extracted from the I-V characteristics.

CONCLUSIONS

A growth from the melt approach utilizing large-amplitude short-duration voltage pulses as a crystallization technique is presented. SEM micrographs and I-t, V-t characteristics during the electrical stress suggest that the bridges are melted, and re-solidified upon termination of the stress. TEM analysis is necessary to verify the crystallinity, crystal orientation and defects.

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