A-SI:H BISTABLE MICROBEAMS FOR MEMORY APPLICATIONS

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Abstract

We present recent advance with the use of amorphous silicon as a structural material for the creation of bistable nanowire. These nanowires are designed to be used in a non-volatile mechanical memory point. The structure is composed of a suspended slender nanowire clamped at its both ends. When later released, the stressed material relaxes and the beam buckles in a position of lower energy. Such symmetric beams, called Euler beams, show two stable deformed positions thus form a bistable structure able to store one bit. Electrodes, placed on each sides of the nanowire, are used to snap the bistable structure (writing, erasing functions) and to measure the position through a capactive bridge (reading function). The paper will show the evaluation of the amorphous silicon deposited by means of PECVD and patterned by electron beam lithography to act as a bistable memory device .

Keywords : MEMS, bistable, memory, beams, nanowire

I- Introduction

Random access memory (RAM) devices are based on solid-state devices developed with microelectronics technologies. These devices must handle functions such as writing reading and erasure with low energy, low voltage and at high frequency. Different approaches exist for solid state RAMs: a capacitor charge in the case of a DRAM, an electrical bistable in SRAMs and a quantity of charge in a floating gate for FLASH memories. Recently some new data storage mechanisms have been used to build advanced memories such as the use of ferromagnetic and ferroelectric materials. In addition, several research have shown the possibility to use a mechanical structure to store a data, and thanks to micromechanics technologies, these mechanical structures, built with small dimensions have shown an interest for building large memory modules with the advantages of radiation hardening for niche markets such as space and military. After a short description of the state of the art of mechanical memories, this paper will show recent developments in the development of an in plane bistable micromechanical memory device.

II- Micromechanical memories

First works in the development of micromechanical memories dealt with surface micromachined in plane large sized designs [2][13][14] and some research on out of plane buckling beams. [1][10].

The company Cavendish kinetics with micromachined memory has done one major achievement. This company has been developing micromechanical memory devices that use a clamped/free electrostatically actuated micro-cantilever as the storage medium. When pulled down in contact with a fixed electrode, the beam tip becomes stuck to electrode, which keeps the beam in a deformed position. By applying a voltage to another electrode, placed above the beam, it is possible to expel the beam and then to perform the erase function. It is recently reported that the process can be integrated on a CMOS 0.18µm technology to produce memory chips. Actuation voltage needed to write one bit can be as low as 1,8V, which is compliant with the CMOS technologies.

Recently another type of memory has been described in the literature [15][16][17]. This new structures uses Carbon Nano Tubes (CNT) as main part of the memory device. Several CNTs are clamped between metallic islands and are suspended over a metallic electrode on top of an insulating layer. By applying a potential difference between the CNT and the metallic electrode, a generated electrostatic force can bend the CNT down towards the electrode, and this bent position can be maintained by some accumulated surface forces such as the Van der Waals force. Competition between the CNTs' restoring forces and the Van der Waals forces cause a bistable phenomenon. The reading function is achieved by measuring the current flowing trough the CNTs that are in contact with the metallic electrode. The erasing function is done by applying voltage to a second electrode located above the CNTs for pulling up. Although this system appears to be very promising, technical difficulties related to the deposition of CNTs at exact position keeps this technology at development stage.

In this paper, we propose a structure based on the use of an in plane bistable buckled beam. Figure 1. shows the schematic of the proposed structure. It is composed of a clamped/clamped beam placed between two adjacent electrodes. The material is stressed during deposition, thus buckling occurs randomly in either position upon release. Information is stored as the mechanical position of the beam.

The writing or erasing function is made possible by electrostatic actuation of the beam with side electrodes. The reading function is made by measuring the capacitance of the structure composed of the nanowire and one of the side electrodes. Because of the stability of the buckled structure, data is stored permanently without the need of electrical powering, thus forming a non-volatile memory.

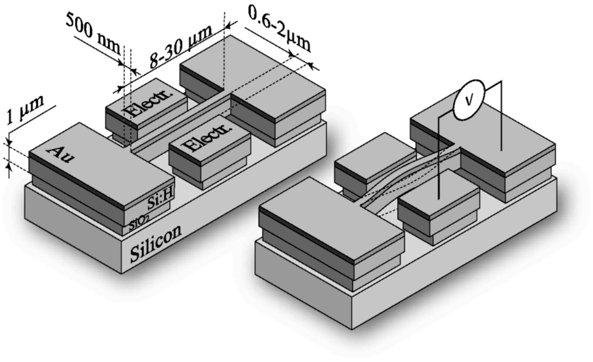


Figure 1. Schematic of in plane pre-stressed buckling beams to be used a non volatile bistable mechanical memory.

III- Fabrication process

The main part of the micromechanical memory devices stands in the stressed layer, which bistability is to be shown upon sacrificial release. In a previous work[1], the structural layer was made with a high temperature thermally grown SiO_2 layer. High stress levels were obtained and bistable behavior have been demonstrated. In this previous case, the structural layer was composed of this SiO_2 layer covered with a thin metal layer. The actuation was performed by means of electrostatic actuation. The covering of the structure by a metal layer and especially the sidewalls covering of the latter was an issue for the efficiency of the electrostatic actuation. In this previous work the actuation was performed mainly by the fringe fields of the metal of top of the nanowire and electrodes. So the idea was to replace the structural material with a conductive layer. So the electrostatic force would act between the sidewalls of the beam and its side electrodes.

We used a Pressure Enhanced Chemical Vapor Deposition technique (PECVD) to build the structure. We start with a 3 inches silicon wafer where a layer of SiO_2 and hydrogenated amorphous silicon (a-Si:H) layer were successively deposited. The thickness of these layers are 0,9 µm. The deposition temperature is 280°C. Next a layer of gold and chromium adhesion layer is deposited by evaporation on top of the SiO_2/a-Si:H layers.

Patterning is done with an electron beam lithographic system. The structure is composed of slender beams of 100, 300 and 500nm nominal width and length ranging from 10 to 60 µm length. A negative ebeam photoresist (Shipley SAL 601) has been used (500nm thick) and exposed at 4µC.cm^2 with a JEOL SEM using the ELPHY quantum system from RAITH Gmbh.

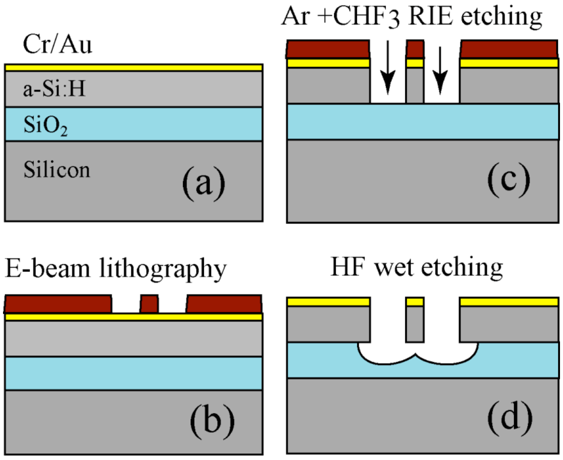
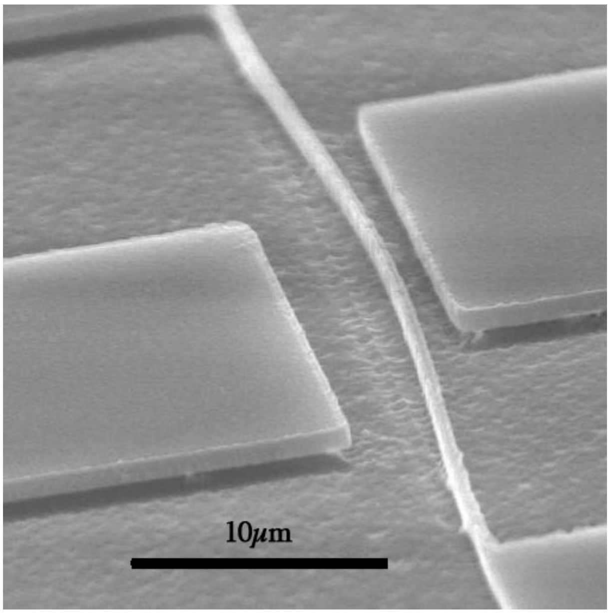


Figure 2. Process chart

The structure is then etched in ICP RIE with first Argon sputtering for the removing the metal layer and then a reactive CHF_3 process to etch the amorphous silicon with an anisotropic profile and producing beams with rectangular cross section.

The final release is performed with wet HF etching of the deposited SiO_2 layer. This step was done with isotropic plasma etch of the silicon in the previous process. The advantage was to get rid of a wet process to avoid sticking issues. In this case the selectivity of the HF etching is high but some sticking problems have been met with long and slender beams. We are currently trying to switch from a wet HF etching to vapor HF etching.



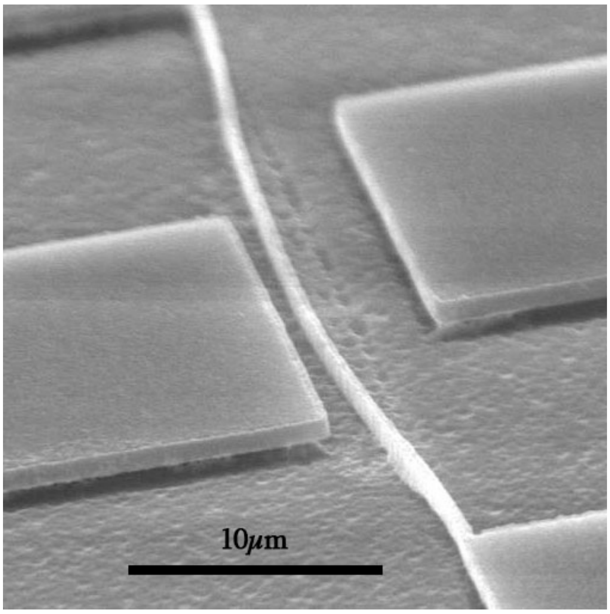


Figure 3. Photography of the electron beam patterning of a clamped/clamped beam made of amorphous silicon. Dimensions: width 500nm, height 1μm, length 50μm.

Figure 2. shows SEM photos of two different suspended beams. Being designed straight, once released they randomly buckles on the left or on the right depending of their initial non-uniformities. They show the typical first order mode shape. The center of the beam, of maximum displacement comes in the vicinity of one side electrode. In the picture we can also notice the position of the side electrodes that are intentionally misaligned regarding the center of the beam. This is done to force the switching of the beam to pass through the second mode shape, thus requiring less energy.

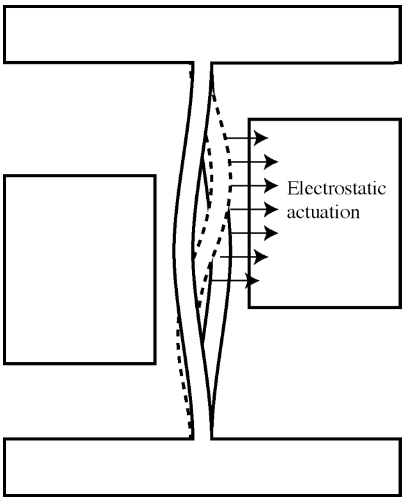


Figure 4. Schematic of the switching from one buckled position to the second stable position through the second mode. .

The use of Amorphous silicon by means of Plasma Enhanced Physical Vapor Deposition (PECVD) technique produces a thick 0,9 μm layer of intrinsic a-Si:H. The material is non conductive and has to be doped to obtain a low electrical resistivity. We plan to use a spin on dopant technique to build the doping profile and thus be able to bias the beam on its whole surface rather than on its only top surface.

IV- Static Buckling Analysis

Our previous work has shown a static buckling analysis of thermally grown SiO_2 beams. We used the same procedure this time to study the buckling of a-Si:H beams. We built different beams with length ranging from 10 to 40μm and the maximum central deflection has been measured with SEM and plotted in Figure 5. The beams reach the buckling criterion for a minimum length of 16μm and shows maximum deflection of about 1μm for the longest 40μm beams. By using the buckling criterion method [1] and for a Young modulus of 100GPa, the compressive stress of the a-Si:H layer can be estimated around 10 MPa.

$$\sigma_{cr} = \frac{\pi^2}{3} E \left(\frac{h}{L_0} \right)^2 \tag{1}$$

Where *E, L_0 and h* are the Young Modulus, beam length and thickness, respectively.

a-Si: H beams have shown a compressive stress that allows them to be used as a bistable nanowire. First fabrication results have shown the release of Si:H slender beams as shown in Figure 3 and 4.

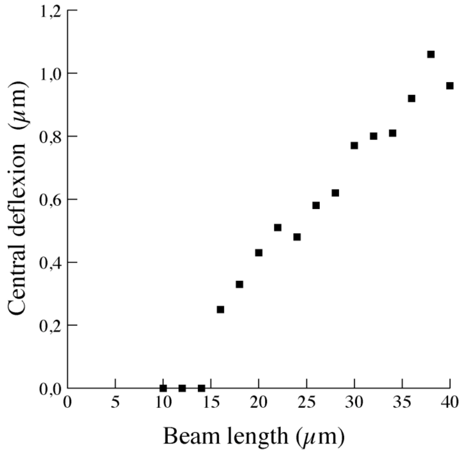


Figure 5. Maximum central deflexion of buckled beams versus length for a width of 500nm and a thickness of 900nm.

V- Conclusions

In this paper we show that we can replace stressed silicon dioxide by a PECVD deposited hydrogenated amorphous silicon. This deposition technique allows obtaining a stressed structural layer that can be etched in slender beams and thus be used as bistable mechanical structure. The stress of the deposited material, that is most of the time a problem for MEMS, is the key factor in this application. The size of achieved beams is for now larger than what has been obtained before by the authors but we plan to go down in dimension with the use of thinner ebeam photoresists and thinner a-Si:H beams. A extension of this work will target the actuation of the beams for data writing function but it needs the material to be doped using a spin on dopant technique. The material at this moment being intrinsic thus non conducting.

VI- References

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