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Foreword

The International Conference on Amorphous and Microcrystalline Semiconductors (ICAMS), which is the premier biennial meeting in this field, covers all aspects of research, from a fundamental understanding of physical phenomena to device technology and applications. First of the New Millennium, and back to France 20 years after the Grenoble Conference, ICAMS 19 took place from 27 to 31 August 2001 on the French Riviera, in the Acropolis Convention Centre, located in the heart of the charming Old Nice. The conference brought together physicists, chemists, materials scientists, and device researchers with a common interest in amorphous, nearly-crystalline and microcrystalline thin film semiconductors. The conference program reflected the continued dominance of hydrogenated amorphous silicon and related alloys in the research and applications of amorphous semiconductors. Controlling the transition and understanding the transport properties of partially crystalline material received particular attention. A significant revival of the chalcogenide field recalled memories of the first ICAMS conferences. ICAMS continues to be inspired by new applications. In addition to thin film transistors and solar cells, photosensor arrays are now well established as commercially viable devices.

Professor Lothar Ley opened the conference with the Mott Lecture, one of eighteen invited talks. Of the 555 abstracts submitted to ICAMS 19, 135 were selected for talks and 150 for posters. Over 340 registrants from 40 countries attended. The proceedings contain 265 papers. The papers were reviewed before and during the conference for scientific content, and for adherence to editorial requirements. We thank all authors for conforming to a very tight schedule for the initial revisions of their manuscripts.

The success of ICAMS is the outcome of efforts shared by many collegues. Foremost are the contributions from a worldwide community of researchers, who chose to present highlights of their recent work. The International Program Committee and the International Advisory Committee provided continuity and guidance. The abstract selection was made in May 2001, by the members of the two Committees at a special meeting held in the French Ministry of Research. Manuscript reviewers carried out their anonymous and unselfish duty under tight deadlines. The delicate work of paper editing has been smoothly performed before and after the conference, by the Scientific Editorial Board and by Professor Joseph H. Simmons, Editor of the *Journal of Non-Crystalline Solids*. Members, but also member companions, of the research groups at Ecole Polytechnique and Ecole Supérieure d'Electricité volunteered their help at the Reception desk and in the Manuscript room. We are most indebted to Ms Alix Berthier from the Ecole Polytechnique foundation FX-Conseil, Ms Liliane Prisca-Morano from PICM laboratory (Ecole Polytechnique) and M. Gérard Vuye from LOS laboratory (Paris 6 University) who provided expert management of the conference. Finally, we express our appreciation to the sponsors for their generous contributions to ICAMS 19 – contributions that ensured the success of the conference.

Our last word as the ICAMS 19 Organizing Committee is to wish a full success to our collegues who are in charge of the next ICAMS 20 conference in Brazil (www.icams20.org).

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Bernard Equer
Denis Mencaraglia
Ionel Solomon
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Amorphous Si TFTs on plastically deformed spherical domes

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Abstract

There is a growing interest in the design and fabrication of flexible and rugged electronics particularly for large-area displays and sensor arrays. In this work, we describe the fabrication of amorphous silicon (a-Si:H) thin film transistors (TFTs) on a Kapton® substrate which can be permanently deformed into a spherical cap shape. This level of strain would crack uniform a-Si:H device films. To prevent fractures in our TFT structure, the silicon and silicon nitride layers of the TFTs are patterned to create isolated device islands. After deformation, these brittle islands can remain crack-free, and the TFTs achieve comparable device behavior despite average strain in the substrate in excess of 5%.

PACS: 85.30.−z

1. Introduction

The development of flexible electronics [1–4] has recently driven much of the research in thin-film semiconductor technologies. Nearly all work to date has focused on cylindrical deformation of thin foil substrates. In such cases, films on the inside of the deformed surface are in compression and those on the outside are in tension, while there exists a plane between these two with no strain (neutral plane) [1,4]. Since the strain on the surfaces (where the devices are) can be kept low by reducing the substrate thickness, tight radii of curvature can be achieved for cylindrical deformation. In this work, we seek to permanently deform planar substrates with amorphous silicon (a-Si:H) thin film transistors (TFTs) into a spherical dome (Fig. 1).

For spherical structures, the strain in the substrate is determined by its shape and is not reduced by thinner substrates. For example, the average strain in the substrate for a spherical dome with 66° field-of-view can be shown by geometrical considerations [5] to be ∼6%. This level of strain exceeds the fracture limit in the device materials and uniform a-Si:H films crack after deformation. Previous results [5] have shown that by patterning hard silicon and silicon nitride layers into isolated islands on soft polyimide substrates, the brittle islands can remain crack-free despite average strain in the substrate in excess of 5%. When the device islands are detached, most of the deformation takes place in the inter-island region and the substrate flows underneath the hard islands. The strain in the semiconductor island is therefore reduced. The maximum island size is a function of the material properties of both the island and substrate. In this work, in order to achieve the maximum island size without fracture after

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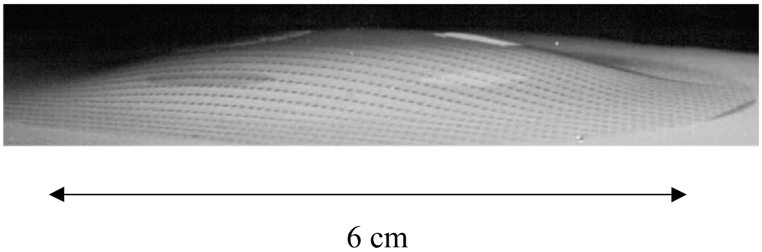

Fig. 1. Polyimide foil with a-Si/SiN_x islands after deformation to a spherical cap shape with a ~66° field-of-view.

deformation, we not only pattern the semiconductor material into individual islands but also etch deep (~8 μm) into the substrate to create the device on a polyimide mesa structure (Fig. 2). Here we report the TFTs' characteristics before and after the substrate is deformed into a spherical dome with field-of-view up to 66°.

2. Experiments

The TFTs have a bottom gate, back-channel etch structure as shown in Fig. 2. 50 μm thick Kapton® E polyimide foils are used as substrates. All TFT silicon layers were deposited using a three-chamber rf-excited plasma-enhanced chemical vapor deposition system at 150 °C [6]. The SiN_x was deposited from a mixture of SiH_4, NH_3, and H_2, the undoped a-Si:H from a mixture of SiH_4 and H_2, and the n^+ a-Si:H from a mixture of SiH_4, PH_3, and H_2. The polyimide substrate was first passivated with a 0.5 μm thick layer of SiN_x. This layer planarized the polyimide surface and also served as a barrier against the chemicals used in the processing. A 100 μm thick Cr layer was thermally evaporated and wet-etched to create the gate electrode. The TFT tri-layer consisted of 360 nm of SiN_x, 200 nm of undoped a-Si:H, and 50 nm of n^+ a-Si:H. A 100 nm thick Cr layer was thermally evaporated and wet-etched to define the source–drain pattern of the transistor. Next, the active region was defined by lithography, and the undoped a-Si:H was etched by reactive ion etching (RIE) in a mixture of SF_6 and CCl_2F_2. In the photolithographic step, the SiN_x pattern was defined and etched in a mixture of CF_4 and O_2. This RIE step etched through both the gate dielectric layer and the SiN_x passivation layer to the substrate to create isolated devices islands. Meanwhile it also etched windows into the SiN_x gate dielectric layer to create openings for the gate contact pads. Next, the polyimide substrate was etched by O_2 plasma. The photoresist (from the previous SiN_x lithography step) and the device islands themselves served as masks to define the mesa pattern. Finally, RIE in CCl_2F_2 was used to remove the n^+ a-Si:H outside of Cr source–drain contact regions. At this stage, arrays of TFTs with different SiN_x island sizes (from 30 to 120 μm) were completed on the planar substrate. In addition, a TFT sample without the O_2 plasma step was also prepared simultaneously for post-deformation yield comparison. Device characteristics of these TFTs were measured before deforming the substrate into a spherical dome. In Section 3, we will discuss the pre- and post-deformation device characteristics.

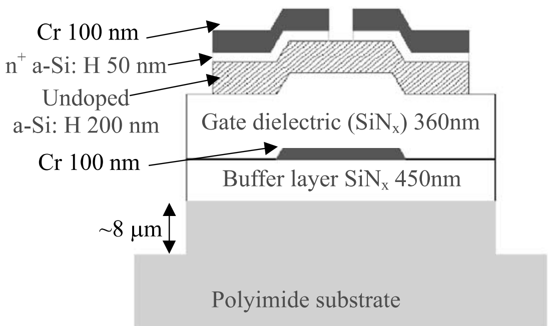

Fig. 2. Cross-section of the TFT structure.

To perform deformation, the substrate was placed over a circular hole and clamped by a circular ring of 6 cm in diameter (Fig. 3). Pressurized gas was then used to deform the material inside the

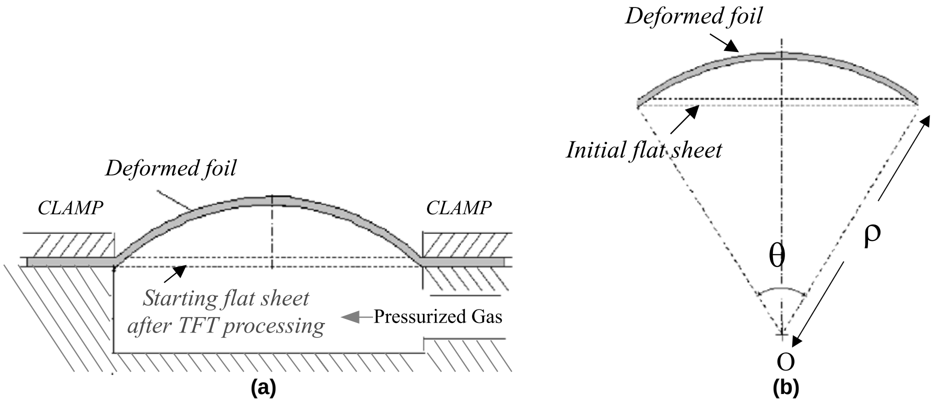

Fig. 3. (a) Design of the apparatus used for deforming thin foil substrates. (b) Schematic cross-section of the foil before and after deformation. Point ‘O’ is the resulting center of curvature of the cap, and subtended angle θ is the field-of-view [5].

clamped ring into the shape of a spherical dome [5]. The field-of-view of the final spherical dome is a function of the pressure we apply. In the first experiment, we deformed the substrate into a spherical dome with a 36° field-of-view (average strain in the substrate ~1.5%) when the pressure was applied. Because the strain was low, the deformation in the substrate was elastic. After the pressure was released, the substrate returned to its original shape. The TFTs' characteristics after this elastic deformation were measured. The substrate was then deformed again into a spherical dome with a 50° field-of-view (average strain in the substrate ~3%). The deformation was permanent, and again the TFTs' characteristics were measured. During measurement, the substrate was mounted to a solid spherical dome to prevent local deformation due to the probe tips. Finally, the substrate was deformed into a spherical dome with a 66° field-of-view (average strain in the substrate ~6%), and the TFTs were measured again.

3. Results

During deformation, the substrate is in constant tension. The TFTs will fail mechanically if the TFT layers crack. The fracture begins at the thinnest region of the island, the contact pad, because it only has the first two layers (buffer SiN_x and the gate metal) of the device structure (Fig. 4). This is because the mechanical strength of the island depends on its thickness. In this experiment, for the sample fabricated without the additional O_2 plasma (without deep-etched mesa structures in the polyimide substrate), the TFTs with SiN_x islands larger than 30 μm fractured after the first plastic deformation (50° field-of-view spherical dome) (Fig. 4). For the sample with polyimide mesa structures, TFTs with SiN_x islands smaller than 90 μm remained crack-free after the final 66° field-of-view deformation.

Fig. 5 shows the characteristic curves of the TFTs on polyimide mesa structure before and after the substrate was deformed. The device shown here is on a 40 μm SiN_x island with gate length $L = 4$ μm and gate width $W = 14$ μm.

Fig. 6 summarizes the results of the TFTs' characteristics before and after deformation. The

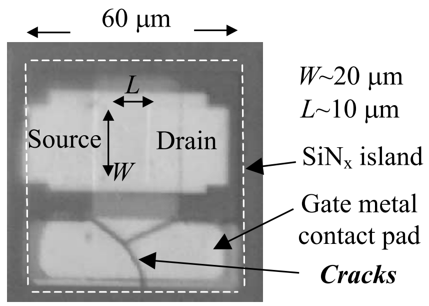

Fig. 4. Optical micrograph of fractured 60 μm device island after deformation to a 50° field-of-view spherical dome. The fracture begins at the gate contact pad region.

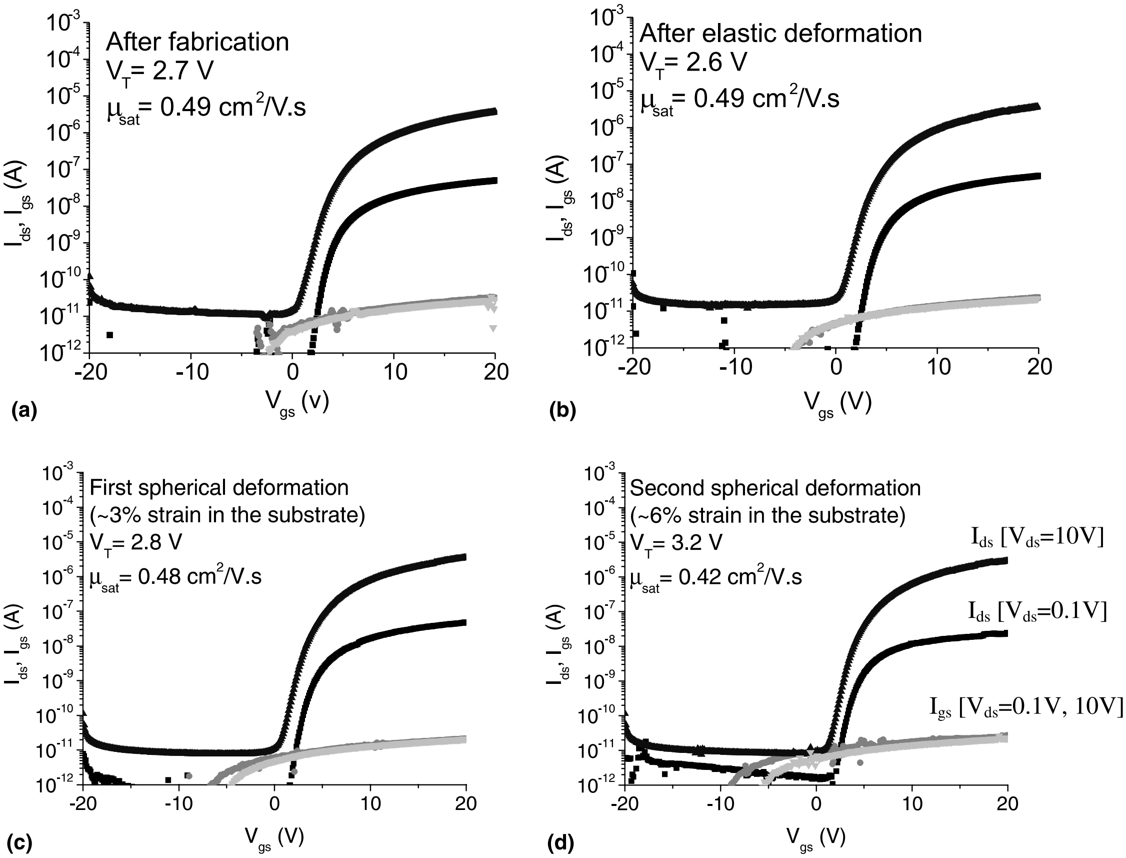

Fig. 5. TFT characteristics. The device shown here is on a 40 μm SiN_x island with gate length $L = 4$ μm and gate width $W = 14$ μm. (a) After fabrication. (b) After elastically deformed into a spherical dome with ~1.5% strain in the substrate, and then released to relax the substrate to its original planar form. (c) After plastic deformation into a 50° field-of-view spherical dome (~3% strain in the substrate). (d) After plastic deformation into a 66° field-of-view spherical dome (~6% strain in the substrate). The TFT is still well behaved with comparable electric performance after each deformation step.

threshold voltage, V_T, and the saturated electron mobility μ_n, are calculated from the transfer characteristic at source–drain voltage $V_{ds} = 10$ V. ~10% increase in V_T and ~10% decrease in μ_n were observed. No substantial changes in the off-current (the smallest source–drain current at $V_{ds} = 10$ V) and the gate-leakage current (the source–gate current for $V_{ds} = 0.1$ and 10 V) were recorded.

4. Discussion

The TFTs are under tension during deformation. To estimate the strain in the silicon islands, we used a commercially available finite element analysis program, ABAQUS, to examine the strain distribution in the thin film island/substrate structure. We measured the stress–strain parameters of the polyimide substrate at room temperature and modeled the silicon nitride and amorphous silicon as both having a Young's modulus of 200 GPa. For simplicity, round islands were modeled. We assume that the volume of the substrate is unchanged, and the substrate stretches 6% in length after deformation. Fig. 6 shows the strain at the center of the island (where it is maximum) as a function of the island size for 0.5 μm thick silicon islands on a 50 μm thick polyimide substrate calculated by the finite element analysis. The maximum strain in the island increases with the island

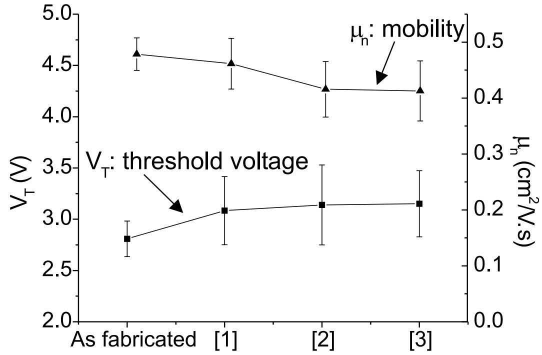

Fig. 6. Threshold voltage (V_T) and electron mobility (μ_n) in the saturation region after each deformation. (1) Substrate was elastically deformed. (2) Substrate was deformed into a 50° field-of-view spherical dome. (3) Substrate was deformed into a 66° field-of-view spherical dome. ~10% increase in V_T and ~10% decrease in μ_n were observed.

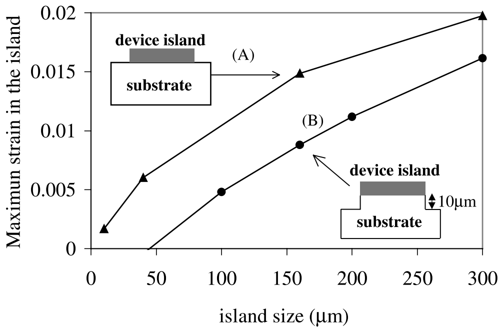

Fig. 7. Finite element analysis of the maximum strain in the island as a function of the island size for 0.5 μm thick circular silicon islands on 50 μm thick polyimide substrate after the substrate is deformed with 6% strain. (A) Device island on uniform polyimide substrate. (B) Device island on polyimide mesa substrate.

size, and etching into the substrate to create the mesa structure reduces the strain that the islands endure when the substrate is plastically deformed. In our experiment, for the mesa structure sample, islands smaller than 90 μm were still intact after the final deformation. Modeling (Fig. 7) shows that in this case the maximum strain in the islands is around 0.5%. We conclude that the critical strain at which the TFTs fail mechanically is approximately 0.5%. This is consistent with previous results in which a-Si:H TFTs were subject to uniaxial tension by cylindrical deformation [4]. Further work is underway to measure strain distribution in the islands and to relate the strain to electrical performance.

5. Conclusion

In this paper we demonstrate TFTs on a plastically deformed substrate with a spherical shape. By patterning the a-Si:H and SiN_x into isolated islands on a polyimide mesa structure, TFTs smaller than 90 μm square islands remain crack-free after the substrate is deformed into a spherical dome with a 66° field-of-view. The maximum tensile strain in the TFT islands is approximately 0.5%. TFTs after such deformation still function properly without significant changes in electrical performance. This work shows that the deformation of circuits fabricated on thin foil substrates is a promising approach for the development of electronics on surfaces with arbitrary shapes.

Acknowledgements

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