Reliability Investigation of Viable Device Structures for Future Flexible Electronic Applications

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Recently, flexible electronics has garnered increased attention. Ultimately, the flexible era aspires to have integrated circuitry that is totally flexible (i.e., flexible memories, processors and batteries). There is significant interest in inorganic flexible devices because organic semiconductor-based materials and circuits do have some lingering challenges, which include: 1) the materials are moisture and temperature sensitive which makes them less reliable over time, 2) good N-type channel materials have yet to be identified, and 3) performance is limited by low carrier mobility [1].

Therefore, investigating inorganic flexible electronic technologies are vital for future flexible applications that require higher performance. Two approaches that are currently being evaluated are zinc oxide (ZnO) based thin-film transistors (TFTs), and complementary metal-oxide-semiconductor (CMOS) devices on flexible silicon fabric (ref). Thin film transistors are key active components in transparent, low-cost, flexible and large area applications. Also, having the ability to fabricate high performing, conventional CMOS technologies on a flexible silicon substrate could enable significant technology breakthroughs since Si typically out performs other thin-film, active layer materials. When high performance is required in conjunction with large area, low cost requirements, co-integrating a flexible Si-based CMOS controller on a large flexible substrate with its own devices may be an option. In order for these technologies to find their way into future technology innovations, examining the reliability is important.

Among flexible semiconductors, ZnO is one of the potential candidates to be used as an active layer in TFTs due to its transparency, inexpensive processing and noteworthy electrical performance [2-4]. Given the potential use of ZnO as an active layer in these applications, it is necessary to understand ZnO-TFTs reliability (e.g., threshold voltage, V_T, instability) in order to further optimize these devices. Therefore, we report on the influence of gate dielectric thickness and source-drain (S-D) metal type on variation of mobility and V_T instability in ZnO thin films transistors (Figs. 1 and 2). The ZnO transistor parameters were evaluated before and after electrical stress for a series of HfO_2 gate dielectric thickness values between 15 nm and 90 nm. V_T shifting (ΔV_T) before and after stress is associated to negative charge trapping is at the ZnO-HfO_2 interface. Saturation mobility (Fig. 2b) increases as the dielectric thickness decreases, with the highest mobility (5 cm^2/V-s) for the thinnest dielectric (V_D = 5 V). V_T increases with increasing dielectric thickness and is attributed to charges in the bulk of the dielectric (Fig. 2c) [5].

For flexible silicon, an advancement over the silicon-on-insulator (SOI) layer removal process has been proposed as an alternative to the SOI peel off process that uses Si (100) wafers and CMOS compatible processing to obtain flexible silicon substrate at a 10X cost reduction over the SOI wafer approach [6]. Fig. 3 briefly outlines the fabrication release steps, and Fig. 4 shows the bent flexible Si fabric after release.

We study the reliability of devices built on the released flexible silicon substrate in comparison to unreleased devices built in the same run and on the same Si (100) wafer to minimize process variations. The major physical difference between released and unreleased devices is the presence of release holes. Our focus is to deduce the effect of such holes on device reliability as suggested by ramped voltage (V_{ramp}) breakdown (V_{bd}) and TDDB analysis of released versus unreleased devices (Fig. 5). The devices

under test are MIMCAPs built using ALD of 20 nm Ta/ 10 nm Al_2O_3/ 20 nm TaN and sputtered 200 nm Al electrodes for probing.

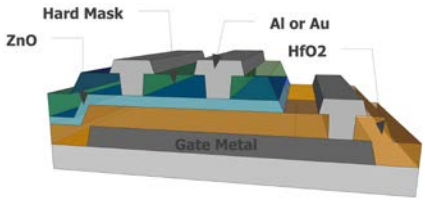

Fig. 1. ZnO TFTs fabricated in this work.

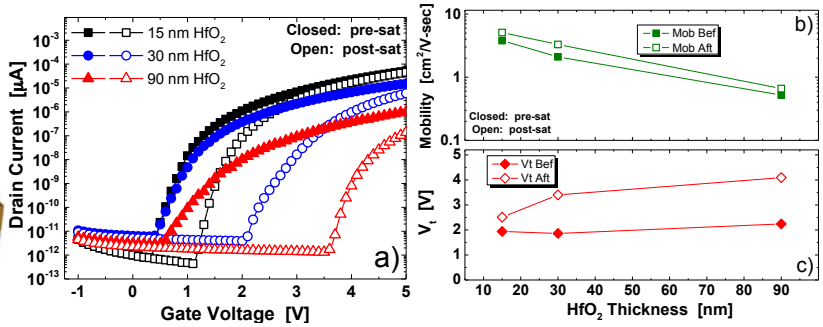

Fig. 2. a) Transfer curves (I_D-V_G) in saturation before and after the device is stressed for three HfO_2 dielectric thicknesses; b) Mobility and c) V_T variation in terms of HfO_2 dielectric thickness.

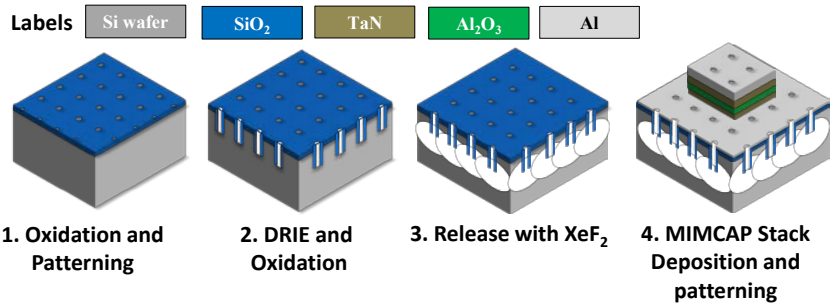

Fig. 3. Releasing of flexible silicon fabric: 1) Thermal oxidation on Si (100) followed by holes patterning; 2) Deep reactive ion etching of Si using the Bosch process followed by another thermal oxidation step for oxide spacer formation; 3) Final release step of the flexible fabric using isotropic XeF_2 etch; 4) MIM capacitor fabrication.

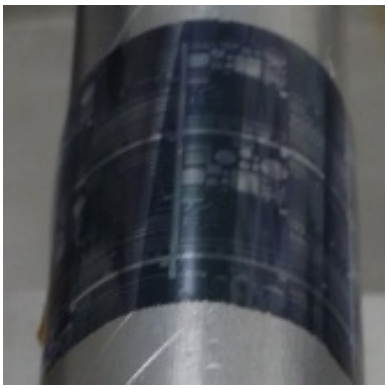

Fig. 4. Flexible silicon fabric bent at a 1.5 cm bending radius without breaking.

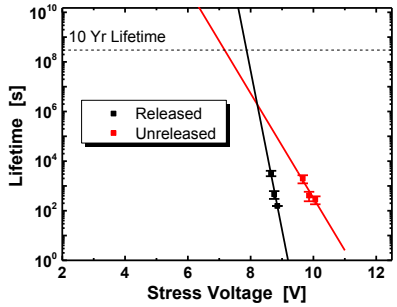

Fig. 5. Lifetime projections of released and unreleased MIMCAPs showing an improvement of the released devices' lifetime over unreleased for operational voltages lower than 8.2V while both devices exceed the 10 years lifetime at operational voltages lower than 7 Volts.

References

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