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Hydrogen passivation on Sequential Lateral Solidified poly-Si TFTs

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ABSTRACT

The present work investigates the effects of hydrogen passivation on the electrical performance of Sequential Lateral Solidified (SLS) poly-Si TFTs by analyzing the dependence of electrical properties on temperature. Under hydrogenation the density of states in the band gap is sufficiently reduced. Analysis of the thermally activated parameters reveals that although previous studies suggest poor passivation of tail states, in SLS TFTs the passivation rate is significantly improved. Moreover, devices subjected to hydrogenation for a longer time exhibit a higher threshold temperature for the thermally activated mechanisms and a lower threshold voltage temperature shift (ΔV_T). It is also found that mobility is almost doubled, which taken into account that previously reported values in laser crystallized films are of the order of 10%, is quite a notable result.

1. Introduction

The electrical properties of polycrystalline silicon Thin Film Transistors (poly-Si TFTs) are strongly restricted by the presence of continuous distribution of states in a poly-Si band gap, usually called DOS (Density Of States). DOS consists of deep level states, caused by dangling bonds mainly located at grain boundaries and at the poly-Si/SiO_2 interface and tail states near bands edges caused by distorted bonds in the grain area [1].

A common technique to eliminate the density of the band gap states and thus to improve the device performance is hydrogen passivation. Initially it was assumed that hydrogen passivates only Si dangling bonds and thus reduces deep states density. However, as presented by optical and DLTS experiments hydrogen also breaks and passivates the Si–Si distorted bonds which are responsible for the shallow states [2]. The effects of hydrogenation on the room temperature electrical behavior and reliability of TFTs fabricated by various crystallization processes have been reported by several authors [3–6]. Although hydrogenated TFTs exhibit improvement of electrical performance, the passivation efficacy has been found to depend on the polycrystalline silicon microstructure. More accurately the propagation of hydrogen at grain boundaries is faster than hydrogen diffusion in the grain area, a process that is controlled by the intra-grain defects thus the grain crystal quality [4]. The grain size and intra-grain crystal quality in polycrystalline silicon films are determined by the crystallization process used to transform the initially deposited amorphous film in polycrystalline film.

The aim of the present work is to investigate the effects of hydrogen passivation on the electrical performance of Sequential Lateral Solidified (SLS) poly-Si TFTs by analyzing the dependence of electrical properties on temperature. The SLS technique allows the fabrication of elongated high quality grains resulting in very high performance TFTs and appears to be increasingly becoming the industry standard [7].

2. Experimental

Polysilicon n-channel TFTs were fabricated on films formed by the crystallization of amorphous silicon. Hydrogenated a-Si films (a-Si:H) were initially deposited at 320 °C by plasma enhanced chemical vapor deposition (PECVD) on quartz substrates. The a-Si:H films were then subjected to a 500 °C, 2 h anneal to remove the excess hydrogen. The resulting a-Si films were transformed in polysilicon ones by excimer laser annealing, using the sequential lateral solidification process [8,9]. The SLS process was conducted at room temperature by scanning the samples under an appropriately shaped laser beam generated by a 4308 Lambda Physik excimer laser (XeCl, 308 nm) with a discharge frequency of 150 Hz. This process results in a polysilicon film having a structure composed of very long crystal grains separated by roughly parallel boundaries. Films with thicknesses of 50 nm were finally fabricated (Fig. 1).

The devices had a non-self-aligned top metal gate structure. Carrier conduction occurred in the direction parallel to the formed grain boundaries. These device orientations presented a minimum energy barrier to conduction, through the anisotropic polysilicon material. The channel length and width were 8 μm and 200 μm, respectively. A 100 nm thick PECVD SiO_2 film, formed by plasma

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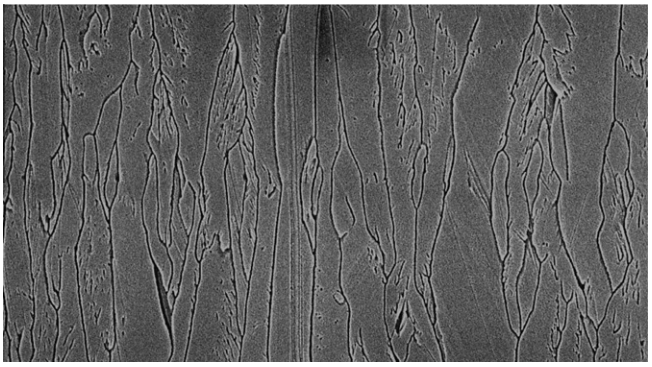

Fig. 1. SEM picture of a polysilicon film. The average grain width is in the order of 0.2 μm.

decomposition of a $SiH_4/N_2O/N_2$ gas mixture at 400 °C, was used as the gate dielectric. The source and drain regions were formed by ion implantation through the gate oxide, with the channel protected by photoresist and the activation temperature was 800 °C. The device body was not intentionally doped. Finally hydrogen passivation was applied in H_2 plasma for 15 and 50 min at 320 °C.

The transfer characteristics have been recorded in the temperature range of 150–440 K, with V_{DS} = 0.05 V. The intercept of a line fitted to the I_{DS}–V_{GS} curve at the point of maximum transconductance g_m, yielded the extrapolated threshold voltage V_T. The field effect mobility μ has been also obtained from the maximum transconductance g_m [12]. The subthreshold slope, S, was extracted from the maximum slope of the I_{DS}–V_{GS} characteristic, drawn in a semilog scale. Bias stress (V_{GS}, V_{DS}) = (7 V, 14 V), with the so-called worst aging (V_{GS} = V_{DS}/2) condition has been applied at room temperature. Additional results are obtained from the application, on the experimental data, of a non-linear, modified Levinson analysis, yielding the flat band voltage V_{FB} [10,11].

3. Results and discussion

The passivation efficacy is determined by the ability of hydrogen to diffuse in the grain boundary area and thus to eliminate Si dangling bonds and in the grain area and thus to break and passivate Si–Si distorted bonds. The diffusion process is quite complicated and is determined by the relative density of defects located at the boundaries and in the intra-grain area [2]. Previous reported results suggest that the passivation rate for deep traps is higher in comparison to that for the tail states due to poor crystalline quality that suppresses hydrogen diffusion in the grain area [3,4].

The passivation effects on films crystallized by the sequential lateral solidification process are summarized in Table 1.

Estimation of the hydrogenation efficacy on the deep states is evaluating by the reduction of grain boundaries traps (N_{GB}) and the deep states located at the semiconductor insulator interface as well as in the depleted area (D_{it}), obtained by Levinson analysis and the subthreshold swing, respectively [12]. Here it must be pointed out that in poly-Si TFTs both methods should be considered as just an estimation of the density of defects and not as accurate calculations. More precisely the analysis of Levinson assumes the presence of a monoenergetic trap at the grain boundaries, while it is well accepted that the trap states have continuous energy distribution [1]. In spite of this the analysis of Levinson is an assumption that is usually adopted by the TFT community in order to evaluate the grain boundaries trap states and in this paper is also adopted by the authors in order to present an estimation on the efficacy of hydrogenation. Regarding the subthreshold swing method, in poly-Si TFTs average density of the interface and bulk traps in the vicinity of Fermi level is estimated. The reason stems from the fact that in polycrystalline silicon both the interface states and the bulk traps are continuously distributed across the band gap, in contrast to single crystal devices where the bulk traps are discrete. Therefore, the results presented in Table 1 should be considered as a proof of the passivation efficacy on the deep states, rather than an accurate calculation of the state density.

Table 1
Major device parameters values after 15 min and 50 min of hydrogen passivation.

	15 min	50 min
D_{it} (cm^{-3} eV^{-1})	$8.3 * 10^{16}$	$4.6 * 10^{16}$
N_{GB} (cm^{-2})	$6.86 * 10^{11}$	$3.05 * 10^{11}$
E_{swing} (eV)	0.38	0.32
$E_{leakage}$ (eV)	0.54	0.48
$T_{Thres.}$ (K)	300–305	340–345
ΔV_T (mV/K)	−3.8	−2.6

In order to evaluate the passivation rate for the tail states, previous studies assert that this is mirrored on device mobility [3,4]. However this was quite a simplistic assumption. Although field effect mobility is strongly related to the density of intra-grain defects, it is also seriously determined by scattering of carriers at the interface and the grain boundary defects, which are mainly located deep in the band gap. Therefore, in the present study the activation energy of the thermally activated mechanisms [13] has been used in order to evaluate the passivation rate for the deep states over the shallower ones.

In poly-Si TFTs the temperature dependence of the major device parameters, such as the leakage current (Fig. 3) [13,14] and the subthreshold swing (Fig. 2) [13,15], is determined by thermally generated carriers through band gap states. Due to the existence of the continuous distribution of these states the effective generation lifetime is expressed as

$$\frac{1}{\tau_e} = \int_{E_v}^{E_c} \left[\frac{u_{th} N_T(E_T)}{\frac{\exp\left(\frac{E_T - E_i}{kT}\right)}{\sigma_p(E_T)} + \frac{\exp\left(\frac{E_i - E_T}{kT}\right)}{\sigma_n(E_T)}} \right] dE_T \quad (1)$$

where $N_T(E)$ represents the concentration of donor like and acceptor like states at energy E_T and per unit energy interval while $\sigma_n(E_T)$ and $\sigma_p(E_T)$ are the corresponding capture cross sections for electrons and holes, and u_{th} the carriers thermal velocity. Due to the fact that the contribution of each state is thermally activated, it is expected that the effective generation lifetime will be also thermally

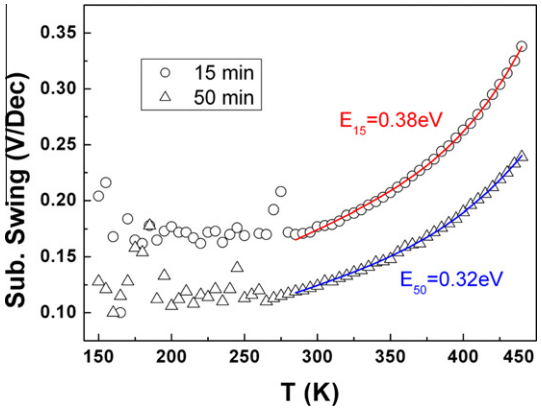

Fig. 2. In poly-Si TFTs the subthreshold swing is found to be thermally activated. The activation energy is related to the energy distribution of states in the band gap. Lower activation energy is obtained by increasing the passivation time from 15 min to 50 min.