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Material related electrical properties of poly-Si TFTs

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Introduction :

Thin Film Transistors (TFTs) are well known devices for their use as pixel elements on flat panel displays. Over the last decades the a-Si technology has been well established and we have enjoyed bright and large flat panel displays on laptop computers and other portable applications. Besides that the a-Si TFTs have the major drawback of low carriers' mobility, thus low drive current. On the other hand the possible futures applications of TFTs, beyond their use on pixels, such as on integrated circuits; require superior electrical properties, comparable with those of single crystal devices [1]. Therefore polycrystalline silicon (poly-Si) has been implemented as the appropriate material for the device body. Poly-Si comprises small grains of single crystal silicon separated by thin grain boundaries. At the grain boundaries the grains of different orientations meet, resulting in an extremely thin amorphous layer or an internal interface. The size and the shape of the grains as well as the widths of the grain boundaries areas are determined by the process applied to transform the initially deposited a-Si to Poly-Si. Different methods have been applied to this transformation, based on the deposition of a-Si films on furnace environment, up to laser irradiations and low temperature processes compatible with the new plastic or organic flexible substrates [2]. Although a lot of effort has been spent and beside that state of the art poly-Si films could consist of long macroscopic scale grains, at least one grain dimension is sub-micron and grain boundaries always co-exist affecting TFTs electrical properties.

The existence of grain boundaries in the active area of poly-Si TFTs is responsible for several undesirable effects on their electrical behaviour. Due to the presence of dangling and distorted bonds in the grain boundaries area, the band gap of poly-Si is occupied by continuous distribution of states [3]. These states determine the device operation by affecting the carriers trapping and generation-recombination processes. Furthermore at the boundaries potential barriers are created and determine the carriers transport properties. Aim of this work is to present an overview of material related electrical properties of poly-Si TFTs, in a large temperature range.

Experimental :

Poly-silicon TFTs were fabricated on films formed by crystallization of amorphous silicon. The initial hydrogenated a-Si films (a-Si:H) were deposited by plasma enhanced chemical vapor deposition (PECVD) on quartz substrates. The resulting a-Si films were transformed to poly-silicon ones by excimer laser annealing (ELA), using the sequential lateral solidification process (SLS) [4]. This process results in a poly-silicon film composed of long crystal domains (grains), separated by roughly parallel grain boundaries (Fig. 1). Here it must be mentioned that the average grain width in SLS films is one to one correlated to the film thickness, therefore devices were processed on films with thickness of 30nm, 50 nm and 100nm. Finally, the die included devices with channel aligned parallel (d0) and vertical (d90) to the boundaries direction [5].

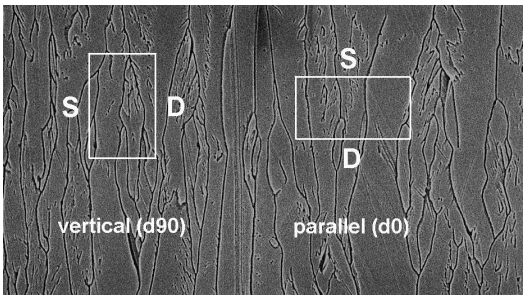

Figure (1) : SEM micrograph of SLS-ELA poly-silicon film and device orientation.

The I_{DS}-V_{GS} transfer characteristics have been recorded in the temperature range of 100 K up to 450 K. Additional information have been obtained by the application on the experimental results of Leninson Analysis [6]

Results and Discussion :

Figure 2 presents the typical temperature influence on the device transfer characteristics. It is clearly noted a shift in the threshold voltage as well as increase in the sub-threshold swing and the leakage current.

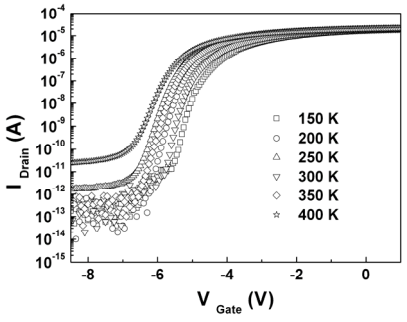

Figure 2: Typical temperature dependence of TFTs transfer characteristics

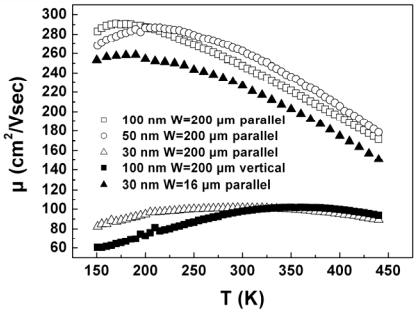

Figure 3: Mobility temperature dependence as a function of film thickness, channel orientation and width

In both cases the increase was found to obey the Arrhenius law and has been attributed to thermal generation of carries through band gap states [7,8], mainly introduced by the presence of dangling and distorted bonds in the boundaries [3]

$$I_{LEAK} = I_{LEAK\,0} \exp\left(-\frac{|E - E_i|}{kT}\right) \quad (1)$$

$$S = A_0 + A_1 T + A_2 \exp\left(-\frac{|E - E_i|}{kT}\right) \quad (2)$$

The corresponding activation energies of the generation mechanisms were found to be material (thickness) related and independent of the channel orientation and width. The results are summarized in table 1 and indicate the presence of deeper states in thicker poly-silicon films.

	Parallel				Vertical	
Film thickness	30 nm (W=200μm)	30 nm (W=16μm)	50 nm (W=200μm)	100 nm (W=200μm)	50 nm (W=200μm)	100 nm (W=200μm)
E(leakage) (eV)	0.56	0.5	0.49	0.2	0.52	0.18
E (swing) (eV)	0.29	0.33	0.27	0.23	0.26	0.23

Table 1: Calculated activations energies for the thermal generation of carriers

Figure 3 presents a set of mobility data, on devices with different characteristics. Higher mobility is obtained on devices with channel aligned in parallel to the boundaries direction. This orientation diminishes the scattering of carriers on the formed potential barriers. Moreover on these devices the mobility further increases as the channel width decreases, indicating enhanced scattering as the number of longitudinal boundaries in the channel increases. Finally regarding the film thickness higher mobility is obtained on devices fabricated on thicker films. This result is expected since wider and higher crystal quality grains obtained on thicker SLS crystallized poly-silicon films [5].

Conclusions :

An overview of material related electrical properties of poly-Si TFTs in a large temperature range is presented. The results suggest that the presence of grain boundaries and extended defect in the device active area are affecting the electrical behaviour through carriers transport and thermal generation. The device mobility could sufficiently increase by the use of appropriate channel orientation and/or dimension. On the other hand it should always taken into account that the properties of band gap states define the activation energy of the thermally activated mechanisms. These mechanisms determine the device performance in particular during high temperature operation.

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