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Influence of trap states on dynamic properties of single grain silicon thin film transistors

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The transient properties of single grain–thin film transistors (SG-TFTs) with high electron mobility have been studied. Overshoot current induced by trap states has been observed in most of the devices. A method of ac measurements has been used to investigate the trap processes. Both transient and ac measurements show that the response of some SG-TFTs with high field effect mobility is dominated by a single trap level. Bias stressing on SG-TFT can induce more trap states and thus change the ac response of the device. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2193049]

Excimer-laser crystallization of amorphous silicon films is a well-established method for producing large-grain polycrystalline silicon thin film transistors (poly-Si TFTs) on glass substrates, which makes it possible to achieve the system-on-panel active matrix liquid crystal display.[1] The poly-Si TFTs have much higher field-effect mobility, typically about 100 $cm^2/V\,s$, compared to that of amorphous silicon TFTs. However, it is still much lower than that of metal-oxide-silicon (MOS) transistors formed on bulk Si wafers. Recently, a development in TFT technology is the fabrication of location controlled single grain–thin film transistor (SG-TFT) by the method referred to as micro-Czochralski or grain-filter process.[2–4] Since there are few or no twin boundaries in the active region of SG-TFTs, higher mobilities of SG-TFTs (400 $cm^2/V\,s$) than standard laser-crystallized poly-Si TFT are obtained. While the static characteristics of SG-TFTs have been studied before, little work has been devoted to the dynamic properties. The dynamic properties of TFTs are very important for circuit operation. Furthermore dynamic measurements are also a good method to get the information on trap parameters,[5,6] which are needed for device simulation. In this letter, we report on the dynamic characteristics of SG-TFTs. Two methods are used: pulsed transient current measurement[5,7] and small signal ac analysis.[8]

N-channel SG-TFTs employed here were fabricated inside location-controlled grains as described before.[2] The gate size is width/length=3.21 μm/2.88 μm. The gate oxide is a 162 nm thick SiO_2 deposited by the low temperature oxide (LTO) process. TFT characteristics of devices fabricate at same condition have big variation, which can be attributed to the presence of twin boundaries with different numbers and different configurations in the channel.[4] We found the field effect mobility of these devices varied from 500 $cm^2/V\,s$ down to 200 $cm^2/V\,s$.

The transient current measurement was described before.[5,7] A train of pulses was applied to the gate by an Agilent 33250A wave form generator. The source was grounded and a constant voltage (V_{DS}=0.1 V) was applied to the drain by a Keithley 230 voltage source. The transient current was amplified by a Keithley 428 current voltage converter and detected by a LC584AL digital oscilloscope. The output signal was averaged over 1000 periods to reduce the noise. The pulse rise time was set to 20 ns, chosen to be comparable with the edge times typically found in TFT digital circuitry. All of the measurement was controlled by a computer with a LABVIEW program. The transient currents were measured with different off times (t_{off}, the time between two pulse applied on the gate) and gate voltage (V_{GS}).

For the ac measurement, a theoretical model was given in a previous paper of the authors.[8] The generation recombination process through traps can be observed by using this method. A small ac voltage $\nu_0 e^{j\omega t}$, where ν_0=0.1 V, was superimposed on a dc gate voltage V_{GS}. A dc voltage, V_{DS}=0.1 V, was applied to the drain and the source was grounded. The frequency dependent ac was measured at the source. We used a Keithley 230 voltage source to supply the dc bias to gate and drain and an EG&G 7260 lock-in Amplifier to supply the ac signal to the gate and detect the ac signal from the source, amplified by a Keithley 428 current voltage converter. The ac was measured under different gate voltages V_{GS} and the measurement frequency ranged from 10 Hz to 10 kHz.

The transient currents of some SG-TFTs have been measured. Figure 1 shows the transient currents of a SG-TFT with the mobility of 400 $cm^2/V\,s$. Off-time dependent overshoot current can be observed. The maximum value of the overshoot above the steady state value is about 10%, which is much lower than for normal poly-Si TFT that is above 50%.[5,6] Though, like in the case of silicon-on-insulator (SOI) devices, the effect is a consequence of the existence of a floating body,[9] the mechanism is quite different in SG-TFTs, owing to the key role played by the trap capture dynamics. After the application of a positive gate voltage, a depletion region forms in the film via electron capture by the traps lying below the final steady state Fermi level. This process

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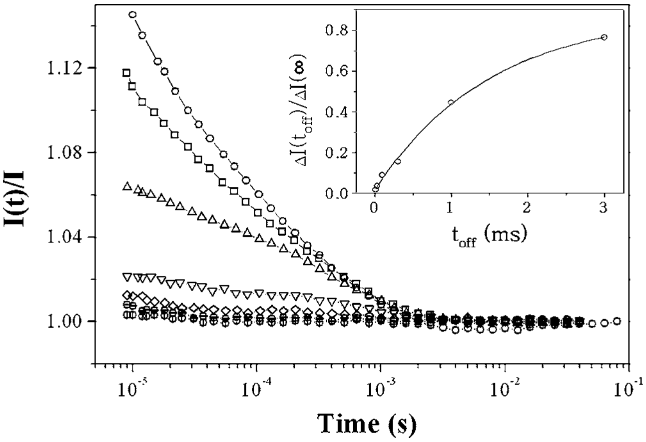

FIG. 1. The overshoot current for a $W/L=3.2\ \mu m/2.9\ \mu m$ SG-TFT with a field effect mobility of 400 $cm^2/V\ s$ for different t_{off}. $V_{DS}=0.1$ V and V_{GS} step=0–7 V. From top to bottom, t_{off}=700 ms, 3 ms, 1 ms, 300 μs, 100 μs, 30 μs, and 10 μs, respectively. Inset: the off-time dependence of the overshoot height $\Delta I(t_{off})$. $\Delta I(\infty)$ is the overshoot for t_{off} tending to ∞.

requires a finite time which depends on the concentration and capture cross section of the trap states. Before the trap states are filled, there are more free electrons in the channel than at steady state which results in an overshoot current. So the decay time of the overshoot current is dependent on the capture time and its height can be expected to be proportional to the concentration of trap states. This result conforms that SG-TFTs have a lower density of trap states than normal poly-Si TFTs. Consistent with this argument, we observed no overshoot in control single crystal SOI devices fabricated with the same gate oxide. We conclude that trap states in SG-TFTs are mostly in the bulk.

As shown in the inset of Fig. 1, the t_{off}-dependent height of the overshoot ΔI can be fitted to a simple equation:

$$\Delta I(t_{off}) = \Delta I(\infty)[1 - \exp(-t_{off}/\tau)], \tag{1}$$

where $\Delta I(\infty)$ is the overshoot for t_{off} tending to ∞ and τ is the relaxation time. We find τ=1.5 ms and that the overshoot height changes little for $t_{off}>100$ ms. So we took $\Delta I(\infty)=\Delta I(700\ \text{ms})$.

The influence of the off time can be explained as follows. The traps below the Fermi level filled with electrons during switch on state. After switch off, when the steady state conditions are reached the Fermi level move back towards the center of gap. All of the trapped electrons above the Fermi level must be emitted into the conduction band. As explained before, the overshoot appears when the trapped electron concentration after gate switch on is lower than that at steady state, the difference being made up by free electrons. Now assuming one dominant trap level with concentration N_T completely full of electrons at the end of switch on pulse, the concentration of empty states $N_T^O(t_{off})$ for $t=t_{off}$ can be written as

$$N_T^O(t_{off}) = N_T[1 - \exp(-t_{off}/\tau)], \tag{2}$$

where τ is the electron emission time from this trap. Since one expects that the excess concentration of free electrons immediately after the rising edge of the next pulse is proportional to $N_T^O(t_{off})$, Eq. (1) results. Hence the transient response of the SG-TFT of Fig. 1 appears to be dominated by a single trap level.

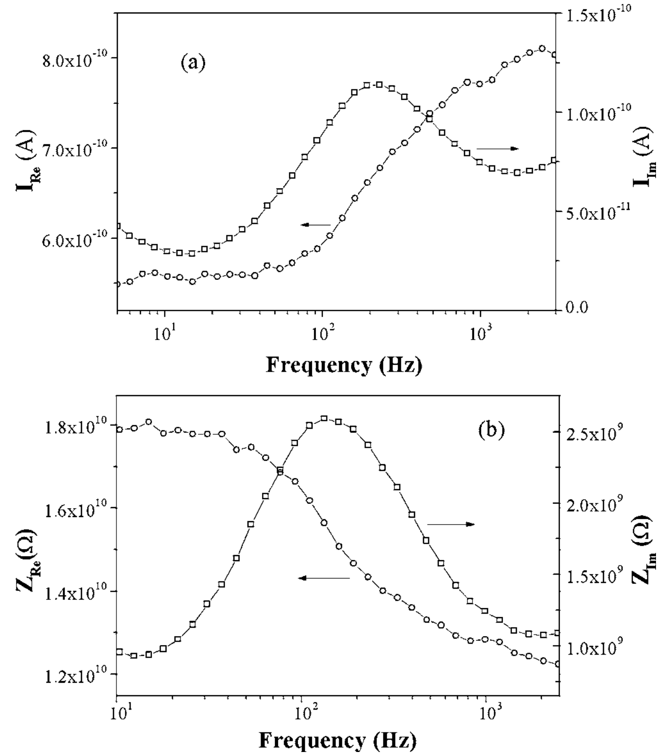

FIG. 2. (a) Real and imaginary parts of the ac measured at source for the sample of Fig. 1. The ac voltage is equal to 0.1 V. V_{GS}=0 V. (b) Real and imaginary parts of the impedance for the sample when V_{GS}=0 V.

The simple relationship between the overshoot height and the off time as described by Eq. (1) only exists in samples with high electron mobility ($\geqslant 400\ cm^2/V\ s$). SG-TFTs with lower electron mobility ($\leqslant 250\ cm^2/V\ s$) showed similar transient properties as poly-Si TFTs,[5] indicating that their transient response is dominated by a distribution of levels and emission times. Since the main difference between samples is number of twin boundaries, we conclude that these boundaries are responsible for the trap states.

ac measurements were performed on the same SG-TFT sample of Fig. 1. As show in Fig. 2(a) and 2(b), the imaginary components of ac and impedance of the system show resonant peaks associated with a step in the real components. The half width of the two resonant peaks is about 1.14 in log axis, which is the value of the resonant process with single relaxation time. This is an additional confirmation that the dynamic behavior of this sample is dominated by a single trap level. The peak frequency in Fig. 2(a) is f_{P1}=220 Hz and in Fig. 2(b) is f_{P2}=135 Hz. The gate voltage varied from 0.0 to 7.0 V. The peak frequencies show no dependence upon V_{GS}. As explained elsewhere,[8] the capture time (τ_c) and emission time (τ_e) of the trap states can be calculated from the peak frequencies of the ac and impedance, giving $\tau_e=1/2\pi f_{P2}=1.2$ ms, and $\tau_c=1/2\pi(f_{P1}-f_{P2})=1.8$ ms. The emission time of the trap states detected by ac measurement is very similar to the τ value extracted from Eq. (1).

ac measurements showed that only the devices with high electron mobility (higher than 400 $cm^2/V\ s$) have a narrow resonant peak. For the devices with the mobility lower than 250 $cm^2/V\ s$, as shown in Fig. 3, no peak but a high background of ac can be observed, which can be explained in terms of the relaxation process with a broad distribution of time constant. Thus multilevel trap states exist in these de-

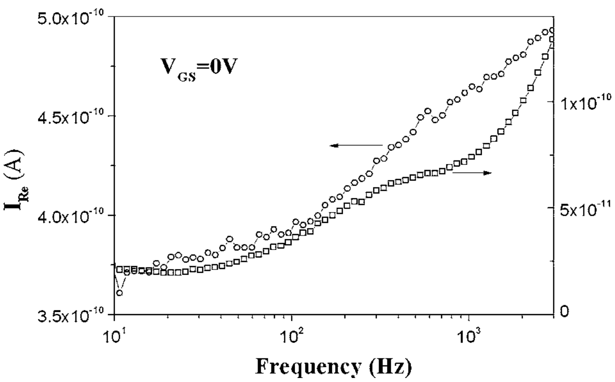

FIG. 3. Real and imaginary parts of the ac measured at source for a sample with the field effect mobility of 250 cm^2/V s.

vices, which is consistent with the conclusion from transient measurements.

The bias stressing effect has been studied by the ac measurement. A SG-TFT with the mobility of 393 cm^2/V s was bias stressed at the $V_{DS}=V_{GS}=10$ V for 10 min and the mobility decreased to about 297 cm^2/V s. The decrease of the effective mobility after stressing indicates that more trap states have been induced in the channel. ac measurement has been done on the device before and after the stressing. As shown in Fig. 4, ac resonant peak can be observed with the peak frequency shifted from 274 to 490 Hz due to the stressing. The capture and emission times of trap states before stressing are $\tau_e=0.72$ ms and $\tau_c=3.1$ ms, as calculated from the ac resonant peak. After stressing, capture time τ_c decreases to 0.59 ms while emission time τ_e remains unchanged. Therefore the density of trap states is about five times higher after stressing according to the equation,[10] $\tau_c=1/\nu_t\sigma N_T$ where N_T is the density of trap states and ν_t is the thermal velocity of free electrons.

The emission time τ_e is a function of capture cross section and trap level,[10] which is given by $\tau_e=1/[\nu_t\sigma N_C \times\exp-(E_C-E_T)/kT]$, where N_C is the effective density of states in conduction band, E_C is the level of conduction band edge, and E_T is the trap level. Therefore same level trap states were induced by stressing since the emission time remains unchanged. However, we find the emission time varies between devices, thus the trap states are different in different devices. We assume the trap states can be attributed to different types of twin boundaries in the channel, such as $\Sigma3, \Sigma9, \ldots$[4]

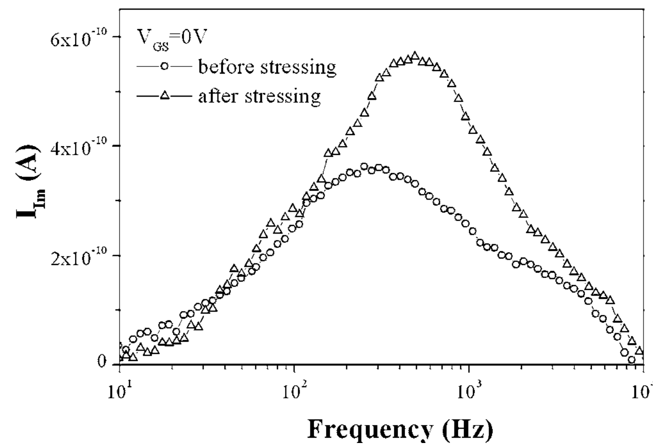

FIG. 4. Imaginary component of ac measured at $V_{GS}=0$ V, for a $W/L=3.2\ \mu m/2.9\ \mu m$ SG-TFT before and after stressing. The stress condition is $V_{DS}=V_{GS}=10$ V for 10 min.

In conclusion, overshoot current is observed in SG-TFTs, which is attributed to traps states in the channel. As confirmed by both transient measurements and ac measurements, most of the devices with high mobility ($\geqslant 400\ cm^2/V$ s) contain dominate single level trap states, which are assumed to be correlated with twin boundaries in the channel.

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