Available online at www.sciencedirect.com

SCIENCE DIRECT®

Microelectronics Reliability 45 (2005) 1161–1166

MICROELECTRONICS RELIABILITY

www.elsevier.com/locate/microrel

Effect of localized traps on the anomalous behavior of the transconductance in nanocrystalline TFTs

M. Estrada [a,*], A. Cerdeira [a], L. Resendiz [a], B. Iñiguez [b], L.F. Marzal [b], J. Pallares [b]

[a] *Sección de Electrónica del Estado Sólido (SEES), Departamento de Ingeniería Eléctrica, CINVESTAV, Av. IPN No. 2508, Apto. Postal 14-740, 07300 DF, Mexico*

[b] *Depart. de Ing. Electrónica, Eléctrica y Automática, Universidat Rovira i Virgili, Avda. Paisos Catalans 26, 43001 Tarragona, España, Mexico*

Received 15 September 2004; received in revised form 1 November 2004
Available online 21 January 2005

Abstract

It has been reported that nanocrystalline and microcrystalline devices show an anomalous behavior in the transconductance where several rates of increase of the transconductance with applied gate voltage, not present in amorphous TFTs are observed. In this paper we show that the anomalous effect of the transconductance is observed for an acceptor tail states activation energy similar to the normal values for hydrogenated silicon amorphous devices, (a-Si:H), provided that some conditions are met regarding the density of trapped charge in tail and deep states and the density of free charge in the material, which does not necessarily suggest a behavior in between amorphous and polycrystalline. The effect appears if the density of deep tail states, is smaller (higher) than the typical values in a-Si:H. The localized state distribution present in a nanocrystalline TFT prepared by hot wire deposition technique is estimated by comparison of experimental and simulated transconductance curves. In our case a lower density of deep states is obtained, which corresponds with their better light and bias stability.

Keywords: TFT; Amorphous and nanocrystalline silicon; Density of states distribution

1. Introduction

Amorphous silicon hydrogenated (a-Si:H) and polysilicon (poly-Si) thin film transistors (TFTs) have been widely studied because of their applications in LCD [1]. a-Si:H TFTs can be deposited on large areas at temperatures below 300 °C, but have low mobility, in the order of 1 cm^2/Vs and suffer from bias stress instability [1]. In comparison, poly-Si TFTs, where field effect mobility between 10 and 300 cm^2/Vs can be achieved require a low temperature crystallization process [2], which increases the production cost and has still some difficulties when applied to large areas. During the past years, nanocrystalline hydrogenated silicon layers (nc-Si:H) have been deposited at temperatures below 150 °C [3] using the hot wire technique. Fabricated nanocrystalline TFTs (nc-TFTs) show an on/off ratio and field effect mobility similar to the a-Si:H TFTs,

* Corresponding author.
E-mail addresses: mestrada@cinvestav.mx (M. Estrada), binyigue@etse.urv.es (B. Iñiguez).

0026-2714/$ - see front matter
doi:10.1016/j.microrel.2004.12.005

but do not show bias stress nor light instability [3,4]. Another significant difference has been observed in the shape of the transconductance curve g_m. In nanocrystalline devices, g_m starts increasing at some rate until a given value of gate voltage V_{GS}. It continues increasing at a much lower rate until, at another value of gate voltage (Region II in Fig. 1), it increases again with a higher rate toward saturation. This shape shown in Fig. 1 has been observed repeatedly in experimental devices [5–7]. A first approach to understand this behavior was given in [6], where it was obtained from simulations, that the anomalous effect was observed for tail and deep states densities of $1\times10^{21}\,\mathrm{cm^{-3}\,eV^{-1}}$, and $1.5\times10^{15}\,\mathrm{cm^{-3}\,eV^{-1}}$ respectively, if the tail states activation energy was in the range between 0.03 and 0.02 eV. These values are smaller than those usually reported for amorphous devices. As the acceptor tail states activation energy was increased above 0.03 eV or below 0.02 eV the effect disappeared. From these simulations, it seemed that the effect appears for devices showing a behavior in between amorphous and polycrystalline. This analysis, however, was done considering an optical gap of 1.91 eV which is not a normal value neither for amorphous nor for nanocrystalline devices.

In this work, we demonstrate that for devices with a gap of 1.72 eV, the anomalous effect of the transconductance is related to the trapped charge concentration characteristics and can also be observed for acceptor tail states activation energy similar to the normal values for amorphous devices of 0.035 eV, provided that some conditions are met regarded the concentration of trapped charge in tail and deep states (N_{tail}, N_{deep}) and the free charge concentration in the material, (n_{free}).

In order to analyze the influence of the localized state distribution on the anomalous effect of the transconductance curve, n_{free}, N_{deep} and N_{tail}, as well as the sheet free charge density in the channel (qn_s), and the sheet charge induced by deep and tail states, (Q_{deep}, Q_{tail}) were calculated for different distributions of localized states, where the density and energy of acceptor and donor deep and tail states was varied. The optical gap was taken as 1.72 eV, which was the measured value for experimental nanocrystalline devices analyzed in this paper. This measurement was performed on nanocrystalline layer of 150 nm, the same thickness used for the fabricated devices. This value obtained for optical gap of nanocrystaline devices, was the same as for amorphous devices. The following parameters were also calculated for different localized states distributions: (1) the transition voltage when the Fermi level crosses from deep to tail states, V_{tran}; (2) the gate voltage at which the Fermi level reaches conduction band, V_{sa}; (3) the density of charged deep states at Fermi level, G_{F0}. Transfer and transconductance characteristics were obtained using ATLAS [1] simulator. The structure shown in Fig. 2 with a channel length of 50 μm and oxide thickness of 200 nm was used in all simulations for different distributions of localized states.

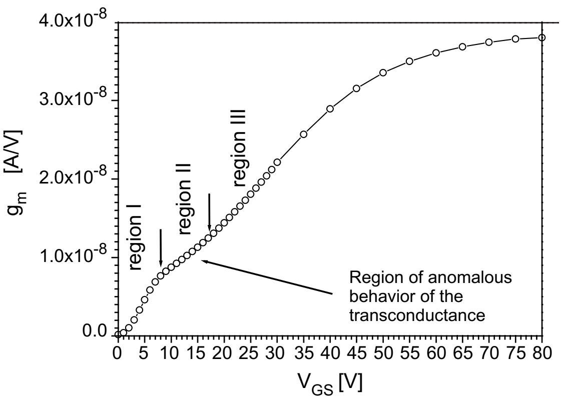

Fig. 1. Anomalous behavior of the transconductance characteristic observed in nanocrystalline TFTs.

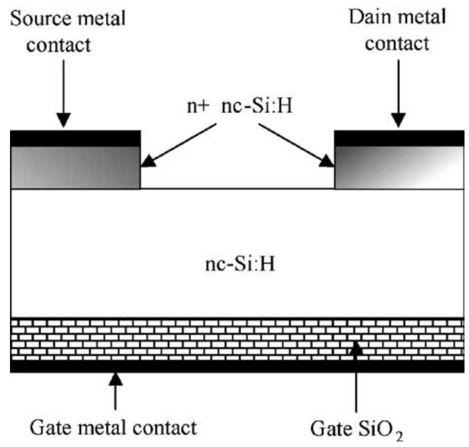

Fig. 2. Cross section of the nanocrystalline TFTs simulated and fabricated by hot wire technique.

In order to compare simulated transconductance curves with measured, a work function difference corresponding to an Al gate contact is considered.

At the same time, nanocrystalline TFTs were fabricated by hot wire technique, having the same cross section shown in Fig. 2. The oxide thickness was 220 nm, the intrinsic film thickness was 150 nm. Bottom gate metal as well as source and drain contacts were aluminum. For simplicity, the gate contact was common for all devices. Although because of this, gate capacitance increases, it has no effect on the behavior of the transconductance curve we are analyzing. Devices have channel length between 10 and 55 μm and width from 22 to 220 μm.

[1] ATLAS is a product of SILVACO International.