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Low frequency noise in intrinsic low pressure chemical vapour deposited polysilicon resistors*

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Abstract. Low-frequency noise measurements were performed on intrinsic low pressure chemical vapor deposited polycrystalline silicon resistors. The current noise exhibits a transition from $1/f$ to $1/f^{0.6}$ behavior with the resistors biased in the linear region. The origin of the noise is related to carrier density fluctuation between conduction band and gap states consisting of deep states lying close to midgap with uniform energy distribution and exponential band tails. From analysis of the experimental data, the quality of the material is characterized with respect to the deposition pressure. When the resistors are biased in the non-linear regime, an additional noise is observed which is attributed to the temperature rise due to Joule-induced heating within the samples.

PACS. 72.80.Ng Disordered solids – 73.50.-h Electronic transport phenomena in thin films – 73.50.Td Noise processes and phenomena

Recently, undoped low pressure chemical vapor deposited polycrystalline silicon (LPCVD polysilicon) has been employed as a basic material for the fabrication of thin-film transistors (TFTs) used in three dimensional integrated circuits and in flat-panel displays. For circuit designers, knowledge of the noise level associated with polysilicon devices at various frequencies, represents a key parameter in circuit design. In addition, the low-frequency noise can allow one to qualitatively characterize the structural quality of the materials, as well as to determine the existence and location of trapping centres. However, noise characterization of polysilicon devices has received limited attention and only few data have been reported in the literature [1,2]. In this paper, low-frequency noise measurements are reported on various undoped LPCVD polysilicon resistors. The experimental results are analyzed and the material quality is investigated by correlating deposition conditions and noise performance.

The polysilicon resistors studied in this work were made from 0.5 μm thick undoped LPCVD polysilicon layers of resistivity of the order of 10^6 Ωcm deposited on oxidized Si substrates at 630 °C and silane pressure varying from 0.5 to 80 mtorr with a constant flow rate of 2.5 sccm (standard cubic centimeter per minute). The deposition pressure, p, affects mainly the mode of growth and the grain size of the polysilicon film [3]. The ohmic contacts were formed by phosphorus implantation and annealing at 600 °C for 4 hours to eliminate the implantation damage. To reduce surface leakage current, the polysilicon films were passivate with a layer of SiO_2 (0.5 μm thick), followed by contact hole etching and Al metallization. The resistors had width $W = 200$ μm and lengths $L = 5$, 10 and 20 μm.

The current-voltage ($I{-}V$) characteristics of the resistors showed a linear behavior in a low voltage region and a non-linear one at higher voltages attributed to Joule-induced heating within the sample [4]. The noise measurements were performed at room temperature with the resistor biased in the linear region as well as in the non-linear region, and in a frequency range where the excess noise is more by one order of magnitude higher than the white noise observed at high frequencies. The current fluctuations were measured through a low noise current-voltage converter (EG&G model 181) connected to a spectrum analyser (HP 35665 A). Figure 1 illustrates typical current noise power spectral density S_I in the frequency noise range from 0.1 Hz to 1.6 kHz, obtained from various polysilicon resistors of the same dimensions ($L = 5$ μm, $W = 200$ μm) biased in the linear region for a constant current flow of I_0=20 nA. In all cases, a transition from $1/f$ to $1/f^n$ (with $n < 1$) behavior is apparent in the measured noise spectral densities. This behaviour is quite different from the behaviour of ion implanted (doped) polycrystalline silicon resistors. In this case, only $1/f$ noise

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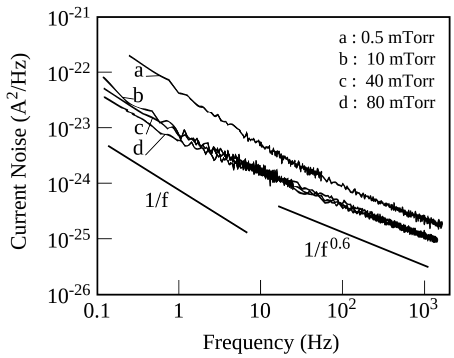

Fig. 1. Typical current noise spectra for resistors of width $W = 200$ μm, length $L = 5$ μm on 0.5 μm thick polysilicon layers grown by LPCVD at various pressures. All the resistors were biased in the linear region with current flow of I_0=20 nA.

was observed [1], and it was explained with the Hooge's empirical law [5] using Kleinpenning's model for Schottky diodes [6]. On the contrary, a $1/f^n$ noise behavior was already observed in intrinsic amorphous silicon layers [7]. This was explained on the basis of random trapping of electrons from the conduction band in gap states with an exponential energy distribution below the conduction-band edge Ec [6].

In polysilicon films, one can adopt the previous model of amorphous silicon, modified by adding a density N_d of midgap states with a given time constants distribution. The exponential band tails can be attributed to the disorder of the silicon lattice (band-length variation and bond angle deviation). Thus, the gap states distribution can be written as

$$N(E) = N_d + N_t \exp[-(E_c - E)/E_t], \qquad (1)$$

where N_t and E_t are the characteristic distribution parameters of the band tails. Following an analysis similar to this of Bathaei and Anderson for the above modified distribution of gap states, we found a distribution of the time constants described by

$$g(\tau)d(\tau) = \frac{N_d}{N_{tot}}\frac{kT}{\tau}d\tau + \frac{N_t}{N_{tot}}\frac{kT}{\tau}(\tau\nu_{ph})^{-kT/E_t}, \qquad (2)$$

where τ is the characteristic time constant for a carrier in a trapping state, ν_{ph} is the attempt to escape frequency for a trap carrier, which occurs in the range $10^{12} - 10^{13}$ Hz [7], T is the absolute temperature, k is the Boltzmann constant. N_{tot} is the total number of trapping centres:

$$N_{tot} = \int_{E_F}^{E_C} N(E)dE = N_d(E_g/2) + N_t E_t \quad \text{for} \quad E_c - E_f \gg E_t. \qquad (3)$$

The total spectral dependence of the current noise $S_I(f)$ is given by [5]:

$$S_I(f) = \left[\frac{q\mu E}{L}\right]^2 N \int_{\tau_1}^{\tau_2} g(\tau)\frac{2\tau d\tau}{1 + (2\pi\tau f)^2}, \qquad (4)$$

Table 1. Distribution parameter E_t of the exponential band tails and density of band tails at the conduction band edge N_t normalized by the deep gap states N_d in LPCVD polysilicon deposited at various pressures p.

p (mtorr)	E_t (meV)	N_t/N_d
0.5	47	2.6×10^5
10	47	1.1×10^6
40	47	1.7×10^6
80	47	2.4×10^6

where μ is the electron mobility, E is the field strength and N is the total number of electrons in the resistor. Using equations (2) and (4), the current noise spectrum can be calculated. The first term of equation (2) gives a 1/f spectrum for $1/2\pi\tau_2 \ll f \ll 1/2\pi\tau_1$. The second term of equation (2) corresponds to an integral which has been calculated by Bathaei and Anderson giving finally a $1/f^n$ spectrum [7]. The final expression for the whole current spectral density is[7]

$$S_I(f) = \frac{kTI_0^2}{2N}\left[\frac{A}{f} + \frac{B}{f^n}\right], \qquad (5)$$

where $I_0 = (q\mu NE)/L$ is the current flowing through the resistor and

$$A = [(N_t/N_d)\, E_t]^{-1} \quad , \quad B = (2\pi)^{1-n} E_t^{-1} (\nu_{ph})^{-kT/E_t} \qquad (6)$$

with $N_t \gg N_d$. The parameters A, B and n for each resistor can be extracted from the experimental data of Figure 1. It is noted that the frequency exponent n was determined in the high frequency region ($f > 100$ Hz) to avoid the error induced by the $1/f$ noise component. Using equation (6) with $\nu_{ph} = 10^{12}$ Hz , we are able to determine the parameter E_t which is directly related to the degree of disorder of the material and the density N_t of the band tails at the conduction band edge normalized by the deep gap states N_d.

Table 1 summarizes the values of E_t and N_t/N_d for all our polysilicon layers. Using the experimental data of Figure 1, from the measured value of the frequency exponent $n \simeq 0.6$ for all samples, we determined the parameter $E_t \simeq 47$ meV, which is independent of the polysilicon deposition pressure. This result is consistent with previous high resolution transmission electron microscope measurements showing an identical disorder in the silicon lattice for $p < 100$ mtorr [4]. The trap ratio N_t/N_d decreases by a factor of about 2 when p decreases from 80 to 10 mtorr due to increase of the average grain size from 27 to 69 nm [3]. When p decreases to 0.5 mtorr, although the average grain size increases to 128 nm, the ratio N_t/N_d decreases drastically by a factor of 10 indicating a corresponding increase in the deep trap concentration. Such an increase in the deep trap concentration can be related to increase of an impurity contamination in the environment of the LPCVD system with constant silane flow rate. This was

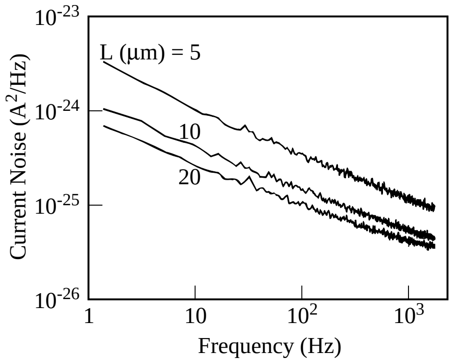

Fig. 2. Current noise spectra for 40 mtorr polysilicon resistors with width $W = 200$ μm and various lengths L biased in the linear region with current flow of I_0=20 nA.

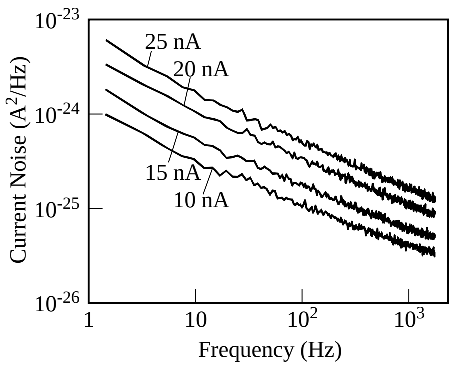

Fig. 3. Current noise spectra for 40 mtorr polysilicon resistor with width $W = 200$ μm and length $L = 5$ μm biased in the linear region with various currents.

also suggested in a recent work to explain the degradation of the TFT performance at very low deposition pressures [3]. The data of Table 1 clearly show that the band tails play a predominant role in controlling the quality of the polysilicon material. Only at very low deposition pressures ($p < 10$ mtorr), the presence of significant amount of deep levels is apparent degrading further the material quality.

The Figure 2 shows the noise spectra for various resistor lengths with a flow of I_0=20 nA. Clearly, the noise decreases with increasing device length due to increase of the total number of carriers. The noise spectra of a typical resistor for different currents are plotted in Figure 3. The noise S_I increases in exact proportion to I_0^2 as confirmed by the plateau of Figure 4 where S_I/I_0^2 is plotted *versus* I_0 for the 0.5 mtorr polysilicon resistor. When the resistor is biased in the non-linear regime (inset of Fig. 4), the noise S_I increases faster than I_0^2. The deviation from the I_0^2 dependence of the current noise can be explained considering the rise in temperature within the material due to Joule-induced heating. Taking into account the temperature rise using the relative current deviation from linearity [8], we estimated from equation (5) the increase of the current noise in the non-linear region. The good agreement between experimental data and the noise calculated after correcting for the temperature rise confirms that the nonlinear $I-V$ characteristic at high electric fields is related to Joule-induced heating within the resistor.

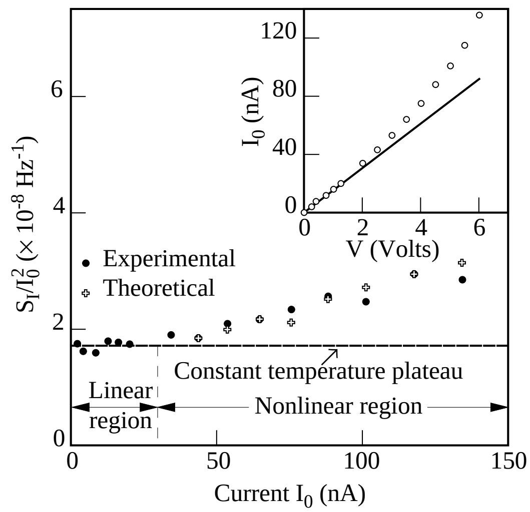

Fig. 4. Normalized current spectral density S_I/I_0^2 at 10 Hz *versus* the current I_0 for a 0.5 mtorr polysilicon resistor with width $W = 200$ μm and length $L = 5$ μm. The inset shows the $I-V$ characteristic of the resistor. The theoretical points (cross) were calculated from equations (5) and (6) after correcting for the temperature rise within the sample.

In conclusion, in undoped LPCVD polysilicon resistors biased in the linear region, the current noise exhibits $1/f^{0.6}$ and $1/f$ dependences. The origin of the noise is related to carrier fluctuation between the conduction band and the gap states with energy distribution uniform for the deep states and exponential for the band tails. Analysis of the experimental data allows us to qualitatively judge the quality of the material. When the resistor is biased in the non-linear regime, the additional current noise is attributed to the temperature rise due to Joule-induced heating effect.

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