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ABSTRACT

We measured the equivalent noise charge of a-Si:H pin diodes (5 ~ 45 μm i-layer) with a pulse shaping time of 2.5 μsec under reverse biases up to 30 V/μm and analyzed it as a four component noise source. The frequency spectra of 1/f noise in the soft-breakdown region and of the Nyquist noise from contact resistance of diodes were measured. Using the conversion equations for a CR-RC shaper, we identified the contact resistance noise and the 1/f noise as the main noise sources in the low bias and high bias regions respectively. The 1/f noise of a-Si:H TFTs with channel length of 15 μm was measured to be the dominant component up to ~100kHz for both saturation and linear regions.

I INTRODUCTION

In previous papers[1~5], we and other groups have covered various applications of reversed biased pin a-Si:H diodes to charged particles, x-ray and γ-ray detection. For charged particle detection in particular, we showed that pin diodes with thin p and n blocking layers and thick (5 ~ 45 μm) i regions could serve as efficient position sensitive detectors. Since the collected signal for minimum ionizing particles is ~80 electron-hole pairs/μm of the i-layer[1], it is obviously important to design the diodes and associated TFT amplifiers with a minimum amount of electronic noise generation. For thin a-Si diodes, 1/f type noise measurements and theory have been published.[6~8] In this paper we discuss measurements of various noise sources originating from thick reverse biased pin diodes and from the thin-film-transistors(TFTs) that we propose to use for readout of pixel or strip detector configurations.

II NOISE AND REVERSE CURRENT IN A-Si:H PIN DIODES

II(a) Experimental

Sample a-Si:H pin diodes were fabricated by the standard PECVD method at Xerox PARC (Palo Alto, CA) and at Glasstech Solar Inc. (Wheatridge, Co). They consist of five deposited layers or glass substrates: the bottom layer is a metallic electrode formed by Cr or tin oxide; the next three layers are n^+-type (~50 nm), intrinsic (5 ~ 45 μm), and p^+-type (~50 nm) a-Si:H layers made by PECVD. The last layer is a top electrode made by evaporation of Cr, Pd, or Al, and it is etched to form circular contacts of radius between 1.5 ~ 3 mm. Sample diodes have equivalent capacitances 10 ~ 250 pF determined by the area of the top electrode and the i-layer thickness.

Since the diodes are reverse biased when used as radiation detectors, the dark current and noise characteristics are investigated under this condition. Diode noise was measured by the two configurations shown in Fig. 1. The first method Fig. 1-(a) measures the equivalent input noise charge in the time domain. The measurement time is set by a pulse shaping amplifier, usually a CR-RC circuit, which performs a differentiation and integration for shaping the signal pulse. The second method Fig. 1-(b) is a set-up to determine the frequency spectrum of the output voltage noise $\langle v_o^2 \rangle$ following a charge sensitive amplifier. Noise data were recorded on a digital oscilloscope and their Fourier transforms were calculated in a PC. Aliasing due to the digital sampling is removed by a Butterworth filter for each measurement frequency range set by the scope. The output voltage noise is related to the input equivalent current noise by the equation,

$$\langle v_o^2 \rangle = \frac{A_w^2}{(\omega C_{in})^2} \times \langle i_{in}^2 \rangle = \frac{K^2}{(2\pi f)^2} \times \langle i_{in}^2 \rangle \qquad (1)$$

where ω is $2\pi f$, C_{in} is the dynamic input capacitance of the preamplifier, A_w is the voltage gain of the wide band amplifier and K is the charge-to-voltage conversion gain of the measurement system (~3×10^{12} V/Coul).

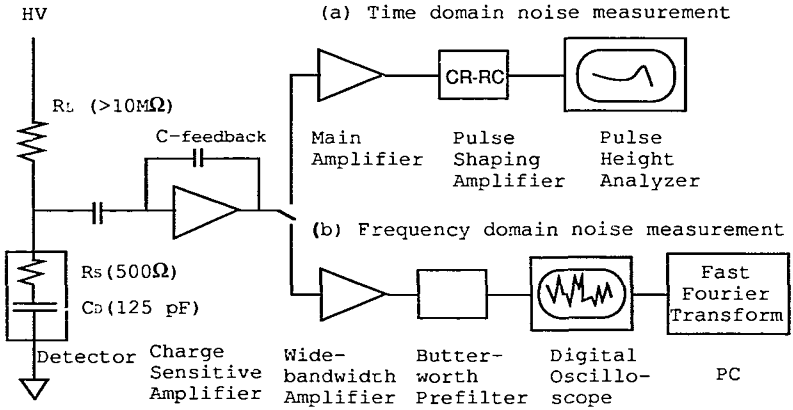

Fig. 1. Schematic of noise measurement set-up

II(b) Results and Discussion

When a-Si:H pin diodes are used as radiation detectors, full depletion is required in order to ensure full charge collection. Usually the operating bias level is set below the point where the pre-breakdown starts shown by a rapid increase in noise. Most of the diodes we have tested show similar I-V and noise characteristics; therefore the discussion here will be confined to measurements on a 26 μm thick pin diode having 3 mm top electrode radius and an equivalent capacitance of 125 pF.

Fig. 2 shows the reverse current density (o) and the noise charge (•) measured with a 2.5 μsec shaping time. The measured noise is flat up to a bias of 15 V/μm and then starts to increase rapidly. The increasing noise has been attributed to some reversible soft-breakdown[9] at the high electric field n-p-i junction area. Our present measurements show that the noise frequency spectra in this bias region are 1/f and are proportional to the reverse current density. This result is similar to an earlier report on 1/f noise from a-Si:H Schottky diodes.[7]

The measured noise data (•) fits very well to the calculated total noise (solid line) from 0 to 30 V/μm bias by the equation

$$N_{tot}^2 = N_{sys}^2 + N_{Rs}^2 + N_{shot}^2 + N_{1/f}^2 \qquad (2)$$

where the terms in the right hand side are separately measured or calculated from their spectra by equations (3), (5) and (7).[10]

(a) system noise N^2_{sys} : It originates mainly from the charge sensitive preamplifier(Amtek A225) and is measured to be 1300 electrons rms by connecting an 125 pF capacitor in place of the diode, in parallel with a load resistor 10 MΩ, whose contribution to the total noise is negligible.

(b) contact resistance noise N^2_{Rs}: The diode has a finite contact resistance R_s of ~500 Ω in series with its equivalent capacitance as illustrated in Fig. 1, which contributes 1500 electrons rms to the system noise. We confirmed that R_s is originated from the evaporated Pd top contact. Simulation by a 500 Ω resistor in series with an 125 pF capacitor gives the same noise charge as the unbiased sample diode and also agrees well with the estimated noise value by the following equation for a simple CR-RC shaping amplifier,[10]

$$N^2_{R_s} = \left(\frac{e}{q}\right)^2 \times \int_0^\infty \frac{\langle v^2_{R_s} \rangle}{\Delta f} C_D^2 |G|^2 \, df \approx \left(\frac{e}{q}\right)^2 \times 4kTR_s \times \frac{C_D^2}{8\tau} \qquad (3)$$

where e is 2.718, q is the electronic charge, τ is the shaping time (2.5 μsec), $\langle v^2_{Rs} \rangle$ is the noise voltage source due to the resistor R_s, and $|G|$ is the transfer function of CR-RC shaper.[10]

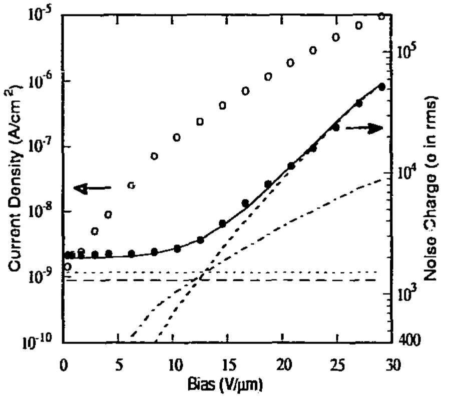

Fig. 2. Reverse current and Noise measurement of a reverse biased 26 μm thick pin diode. Measured noise data (•) is fitted well by the sum (solid line) of four noise components; (a) system noise, (b) contact resistance noise, (c) shot noise of diode, and (d) 1/f noise of diode.

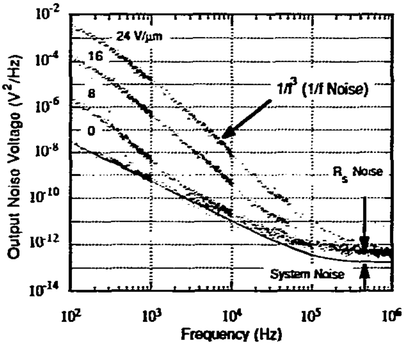

Fig. 3. Noise spectra of a reverse biased 26 μm thick pin diode. $1/f^3$ dependency in output noise voltage spectra is equivalent to 1/f when converted into a parallel current noise source in the diode by the equation (1). Nyquist noise from the contact resistance equivalent to 500 Ω is shown as a white spectrum by an arrow in the figure.

$$|G|^2 = \frac{(\omega\tau)^2}{\left(1 + (\omega\tau)^2\right)^2} \tag{4}$$

Fig. 3 shows the excess Nyquist noise component at high frequency due to this series resistance R_s.

(c) *Shot noise N^2_{shot}: Shot noise of the diode in the time domain is* calculated from the measured reverse current I_r by the equation,

$$N^2_{shot} = \left(\frac{e}{q}\right)^2 \times \int_0^\infty \frac{\langle i^2_{shot}\rangle}{\Delta f} \frac{|G|^2}{\omega^2}\, df \approx \left(\frac{e}{q}\right)^2 \times 2qI_r \times \frac{\tau}{8} \tag{5}$$

(d) 1/f noise $N^2_{1/f}$: The measured output noise voltage spectra $\langle v^2_o\rangle$ under various bias conditions are plotted in Fig. 3 in which $1/f^3$ is found to be dominant at low frequency. Equation (1) show that $1/f^3$ dependence of output noise voltage is equivalent to a 1/f spectrum of input current noise $\langle i^2_{in}\rangle$. The measured magnitude of the $1/f^3$ noise power is proportional to the square of the reverse current so the equivalent input current noise of the 1/f component can be empirically represented by

$$\langle i^2_{in}\rangle = K_d \times \frac{I^2_r}{f}\,\Delta f \tag{6}$$

where K_d is a constant($\sim 3.6\times10^{-8}$) and the measured K_d value decreases from 8×10^{-7} to 8×10^{-8} almost linearly as the inverse of the square of the i-layer thickness from 10 µm to 45 µm. K_d is equivalent to A/N in Hooge's empirical relation for 1/f noise where A is Hooge's constant[11] and N is the total number of charge carriers in the device. The 1/f noise in the time domain is calculated from

$$N^2_{1/f} = \left(\frac{e}{q}\right)^2 \times \int_0^\infty \frac{\langle i^2_{1/f}\rangle}{\Delta f} \frac{|G|^2}{\omega^2}\, df \approx \left(\frac{e}{q}\right)^2 \times K_d I^2_r \times 6\ \tau^2 \tag{7}$$

where the lower frequency limit of the integration was assumed to be about 100 Hz which is equivalent to the trapping level at ~0.6 eV below conduction band. The above equation shows that the 1/f noise contribution can be reduced by decreasing the reverse current, or by reducing the surface field, or by using a smaller shaping time τ.

Since the shot noise is linearly proportional to the current and 1/f noise is proportional to the square of the reverse current, the shot noise is dominant at the lower bias and 1/f noise is dominant at higher bias. At higher bias the diodes start to breakdown irreversibly and are permanently damaged. Most of diodes with i-layer thickness range of 5 ~ 45 µm show similar characteristics to the one discussed here. However some poorer quality diodes have lower onset bias for sharp breakdown behavior.

III 1/f NOISE IN A-Si:H THIN-FILM-TRANSISTORS

III(a) Experimental

Sample a-Si:H TFTs were fabricated at Xerox PARC. They are of the staggered inverted type which has a structure shown in Fig. 4. The gate insulator is Si_3N_4 of thickness 0.3 µm and the channel length is 15 µm. The channel width ranges from 16 µm to 256 µm.

I-V characteristics and noise spectra were measured in a shielded probe station. A HP 4145 semiconductor parameter analyzer was used to measure the dc I-V curves and transfer characteristics. A HP 3561A spectrum analyzer with a low noise current amplifier was used to measure the spectra of the noise current at each bias condition. Then the equivalent input voltage noise $<v^2_{in}>$ was calculated by the following relation.

$$<v^2_{in}> = \frac{<i^2_d>}{g^2_m} \qquad (8)$$

where $<i^2_d>$ is the measured drain current fluctuation and g_m is the transconductance at the bias point.

III(b) Results and discussion

The dc drain current and its fluctuation change linearly with the channel width of the sample TFTs so the discussion here is given for a TFT with channel width of 128 μm. Fig. 5 shows I-V curves for the sample TFT. The measured field effect mobility in the saturation region has a range of 0.4 ~ 0.6 cm^2/Vsec, which corresponds to a range of band mobility of 13 ~ 18 cm^2/Vsec as calculated from the Xerox TFT model[12,13] used in the PSPICE program.

1/f type noise is found to be dominant in the bias and frequency range of interest. The equivalent input voltage noise in the saturation

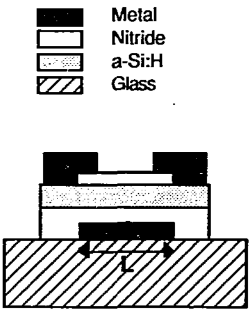

Fig. 4. Schematic diagram of a-Si:H thin-film-transistors made at Xerox

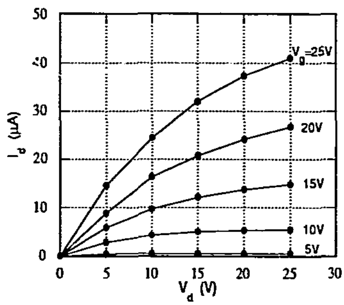

Fig. 5. I-V curves of a-Si:H TFT with L = 15 μm and W = 128 μm

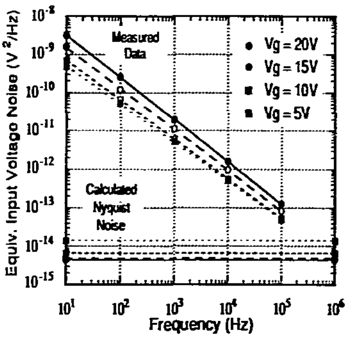

Fig. 6. Gate bias dependence of noise spectra of a-Si:H TFT of L = 15 μm and W = 128 μm when V_d = 20 V

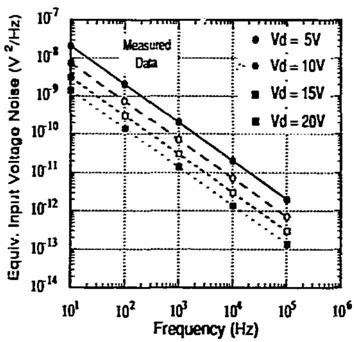

Fig. 7. Drain bias dependence of noise spectra of a-Si:H TFT of L = 15 μm and W = 128 μm when V_g = 15 V

region as shown in Fig. 6 is generally expressed[14] by the equation

$$<v_{in}^2> = K_t \times \frac{I_d^{\beta}}{f^{\alpha}} \Delta f \tag{9}$$

where I_d is dc drain-source current. Measured α and K_t increase slightly from 0.97 to 1.1 and from 1×10^{-6} to 3×10^{-6} respectively as the gate bias increases from 5 V to 20 V. Measured β changes from 0.41 to 0.85 when the frequency changes from 1 Hz to ~100 kHz. The range of β agrees with the empirical Si-JFET model.[14] The Nyquist (thermal) noise due to the finite channel resistance of the TFT was calculated by the following equation in the saturation region,

$$<v_{Nyquist}^2> = \frac{4kT}{(3/2)g_m} \Delta f \tag{10}$$

Fig. 7 shows a steady decrease of the equivalent input voltage noise as drain bias increases from 5 V to 20 V when V_g = 15 V. Similar effects have been observed in crystal-Si MOSFET.[15]

IV CONCLUSION

In reverse biased pin diodes, series contact resistance noise is dominant at low bias and 1/f type noise is dominant in the soft-breakdown region. In order to minimize noise, reduction of contact resistance as well as reverse current is important. For a-Si:H TFTs, 1/f type noise is found to be dominant over the whole operating frequency range. Whether the 1/f type noise is an interface effect or a bulk effect in both a-Si:H pin diode and TFTs is still unclear and requires further investigation.

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