Comprehensive Characterization and Analysis of RTS, 1/f, RF Noise and Power Performances of Schottky-Diode in Standard CMOS

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ABSTRACT

For the first time, we present comprehensive characterization of Schottky-diode in standard CMOS on its DC, low-frequency and RF noise performance. RTS- and 1/f-noises have been characterized, along with RF noise, power performances analysis. Results showed that Schottky diodes in standard CMOS are excellent choices for low-noise, high-speed RFIC applications.

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Abstract

For the first time, we present comprehensive characterization of Schottky-diode in standard CMOS on its DC, low-frequency and RF noise performance. RTS- and 1/f-noise have been characterized, along with RF noise, power performances analysis. Results showed that Schottky diodes in standard CMOS are excellent choices for low-noise, high-speed RFIC applications.

Introduction

For RF/Microwave integrated circuit applications, Schottky diode is an important fast switching device [1-2].However, for Schottky diode fabricated with standard Si-CMOS technology, there is lack of report on its *NOISE and RF* performances. Since the *NOISE* performance determines the system sensitivity and frequency fluctuation in applications of RF-oscillator, -mixer, -switch, and -modulator/demodulator, it is important to investigate the *NOISE* and RF behaviors over a wide frequency range.

This paper reports, for the first time, on the LF-/RF-noise characteristics and power-performances of a standard-Si-CMOS-based Schottky diode.

Major results presented in this work are:

(1) Random-telegraph-signal (RTS) noise was observed, but within a very narrow forward-bias (V_F) range (V_F=0.50-0.68V);

(2) Our results demonstrate that the LF-1/f Flicker noise (<~450Hz) was originated from RTS noise with $\tau_{capture}$ ~0.3ms-~1.9ms. RTS noise mechanism was discussed;

(3) RF-noise performance was examined, and observed min. NF_{MIN} (and noise-resistance) due to the two competing dominant noise-mechanism;

(4) Excellent rectifier characteristics were demonstrated for its high RF-to-DC conversion efficiency.

Fabrication and Characterization

The design and fabrication of Schottky-diode (Al/N^-) were conducted based on a commercial available 0.18µm CMOS process [2-3]. Schottky diode with test pads and the top view of layout with dummy structure were shown in Fig. 1. The Schottky contact was formed between standard contact with metal-1 layer of 0.22x0.22µm^2 arrays and n-well (N_D~2x10^{16} cm^{-2}). P-substrate was grounded. Total diode size is about 6.7µm^2. Fig. 2 shows (a) Schottky-diode device cross-section structure, and (b) its equivalent circuit. The diode structure parameters are shown in Table-1.

Low-Frequency Noise

Fig. 3 shows the DC characteristics under forward- and reverse-bias: the build-in potential V_D is ~0.55V, the junction breakdown voltage V_B is ~9V, the barrier height Φ_B ~0.628 eV, and ideality factor n~1.12.

Fig. 4(a) compares the RTS noise spectrums under different forward biases: V_F=0.48 to 0.70V in a step 0.02V, and each with duration of 18ms. Each bias condition was measured with 10 spectrums to verify the statistical significance. Fig. 4(b) shows two RTS noise zoom-in view at two bias conditions of 0.54V and 0.60V with certain time range of 4ms. The results indicate that the RTS noise behavior exhibited (or being detected) only within a very narrow V_F-window, i.e., between 0.50 to 0.68V. The amplitude of RTS noise is increased from ~0.3nA to ~2nA (Fig. 4(a)). Assuming RTS noise is originated from the barrier height fluctuation due to the carrier-capture and -emission with the electron traps [4], thus average $\tau_{capture}$ is varied from 0.3 to 1.9ms whereas average $\tau_{emission}$ remains Max. ~90µs with the increasing V_F (Fig. 5). This is consistent with the assumption that traps only exchange carriers with the conduction band [5]. The disappearance of detectable RTS noise with higher V_F is due to the gradually shrunk depletion layer.

In the frequency domain, The flicker noise from DC to 51.2 kHz are characterized for V_F = 0.50 to 0.70V (Fig. 6). RTS pulse-width determines the low frequency spectrum bandwidth. The noise-power density for frequency range of DC to ~450Hz exhibits a strong 1/f^2 dependence with Hooge parameter a_H = 7.343e-5 at 64Hz (a_H = 2.246e-7 at 1kHz) in Fig. 7. As shown in Fig. 5, the RTS pulses are in ~ms range, which correlates well with the noise spectrum seen in frequency domain for frequency <~450Hz. Then the RTS noise is believed to be dominant in this frequency range. For a given bias between 0.5-0.68V, Schottky depletion width can still be modulated by the voltage or barrier height fluctuation induced by trapping/detrapping [7].

RF-Noise and Power-Conversion

Fig. 8 and 9 illustrate RF (GHz) noise and noise resistance performance. Over tested V_F range from 0.4 to 0.75V, there is a minimum NF_{MIN} at bias ~0.5V. This occurs due to 2 competing noise mechanisms for different biasing conditions: resistance thermal noise being dominant for bias <0.5V and current noise dominant for bias >0.5V. However, for noise resistance (R_N), the minimum R_N occurs at bias~ 0.6V because the output resistance decreases with bias increasing whereas the diode capacitance increases with the increasing bias. As a result, R_N minimum occurs under biasing before diode resistance and capacitance become dominant.

Fig. 10 shows that the rectifier's voltage obtained from RF-to-DC conversion vs. load resistance (R_{load}) as function of input power. The conversion-voltage can reach as high as 3.7V with an efficiency of 5.5% at input power of 15dBm. The output conversion-voltage saturates for R_{load} ≥50KΩ. Fig. 11 shows the conversion efficiency vs. R_{load}. (Inset) The conversion efficiency peaks at R_{load} ~500Ω regardless of the input RF power, since it is determined by input matching circuit. Fig. 12 shows that the measured and simulated S-parameters. The data show that measured S-parameters are in good agreement with simulated ones. These data show that the schottky diodes in standard CMOS have good RF performances and available for RFIC circuit design solutions.

Summary

The DC, low frequency and RF performances of schottky diode in standard CMOS have been discussed. RTS and 1/f noise were demonstrated, with evidence of RTS noise being a dominate contributor to LF noise (1/f^2) from DC to ~450Hz. From the performance assessment, it is believed that the Schottky diodes in standard CMOS will be excellent devices for low noise and high-speed oscillator, mixer, switch, rectifier, detector, modulator and demodulator applications compared to Si-CMOS transistors.

References

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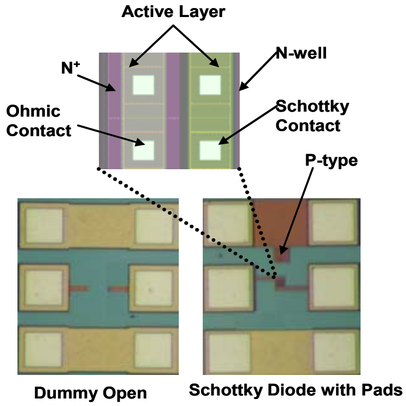

Fig. 1 Layout of Schottky diode. The n-implant contact was placed as close as possible to the Schottky contact (n-well) to minimize the series resistance. The outer ring is a contact to the p-substrate which is grounded to protect substrate diode working forward biasing state. Open dummy structure was used for RF de-bedding purpose.

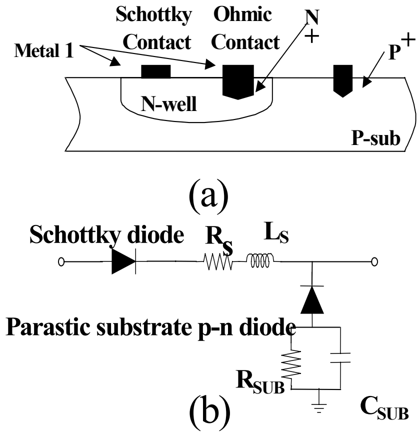

Fig. 2 **(a)** Schematic of Schottky diode; and **(b)** equivalent circuit, there are p-n diode between n-well/p-substrate and associated substrate resistance and capacitance.

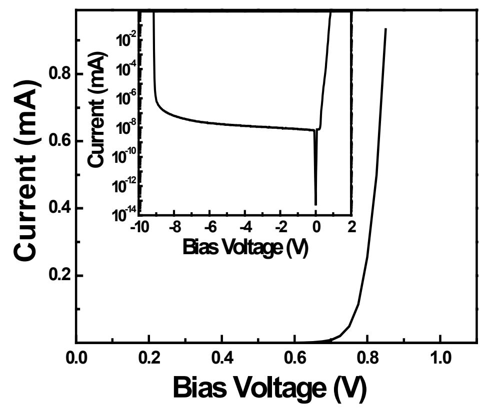

Fig. 3 Schottky-diode's forward I-V characteristics: the built-in voltage V_D is ~0.55V and barrier height Φ_B is ~0.628V. The elements values are listed in Table-1. The data extraction is based on the method in [6].

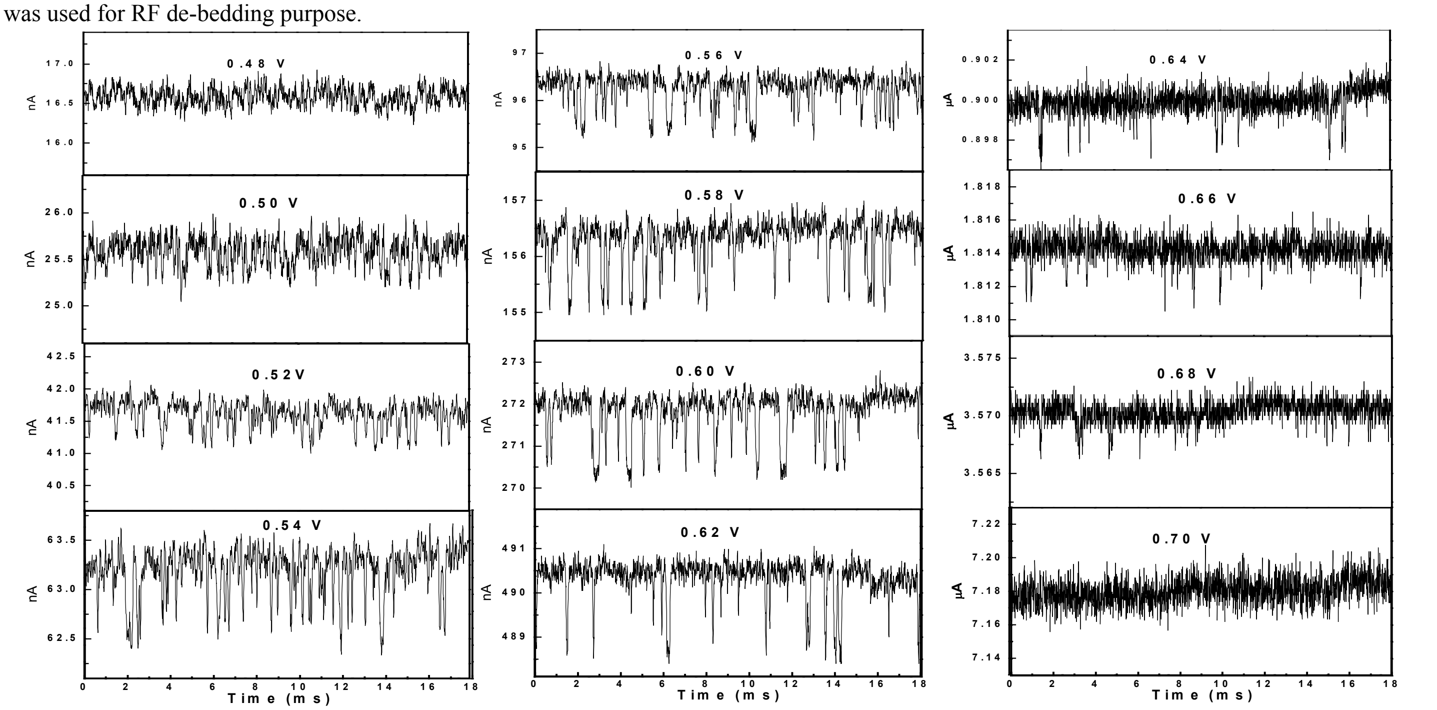

Fig 4 (a)

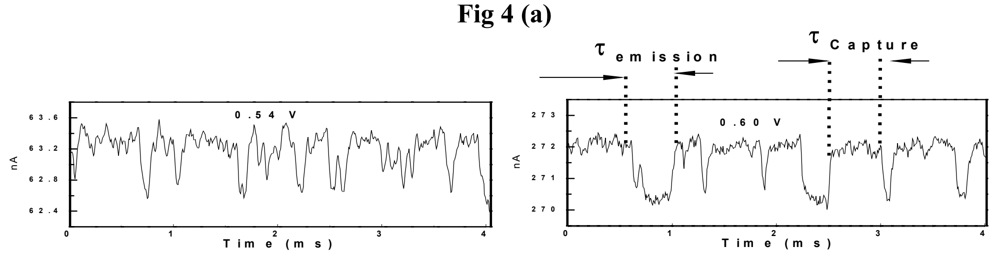

Fig 4 (b)

Fig. 4 RTS noise waveforms obtained under different forward biasing voltage. To characterize Random telegraph signal (RTS) noise and LF noise with minimum parasitic interference, the wire-bonding implementation for the schottky diode was done for good contact due to very small noise current. The cathode of the device was connected ground and the anode was connected to low noise current amplifier which provide biasing for diode and its output coupled to the dynamic signal analyzer. Total 10 times captures (total 10240 points) were carried out at each bias points for RTS noise measurement. **(a)** RTS noise with different bias from 0.48V to 0.70V. **(b)** Zoom-in view at 0.54V and 0.60V with certain time range of 4ms.

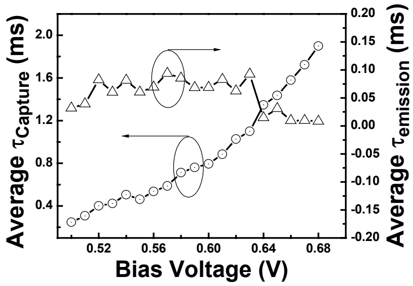

Fig. 5 Average RTS high- and low-current pulse widths ($\tau_{capture}$ and $\tau_{emission}$) vs. bias voltage.

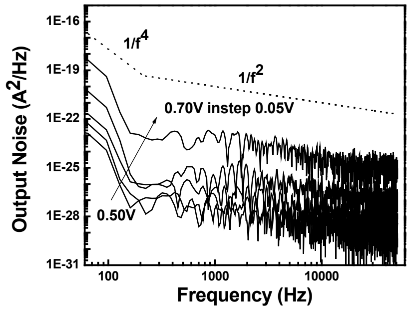

Fig. 6 LF current noise density under different bias voltage.

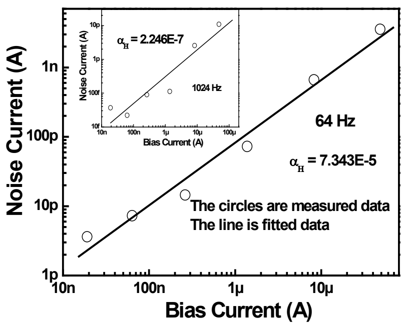

Fig. 7 LF current noise versus bias current at 64Hz and 1024 Hz, respectively. The Hooge parameters are calculated based on the method in [7].

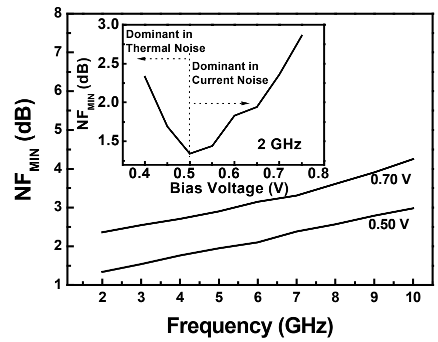

Fig. 8 RF NF_{MIN} vs. frequency under different biasing. Inset illustrates the NF_{MIN} under different bias voltages @ f =2GHz .

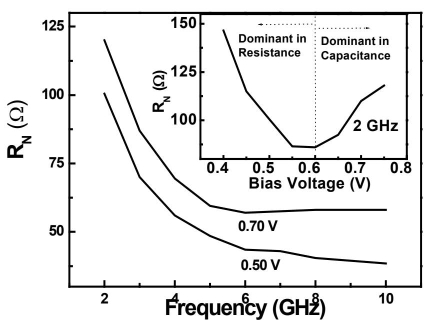

Fig. 9 Noise resistance R_N vs. Frequency. The insert illustrates the R_N under different bias voltages @ f =2GHz.

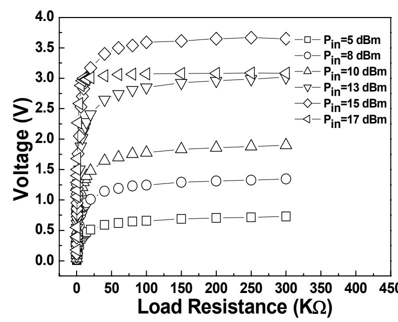

Fig. 10 Schottky diode rectifier RF-to-DC conversion for different input power and load.

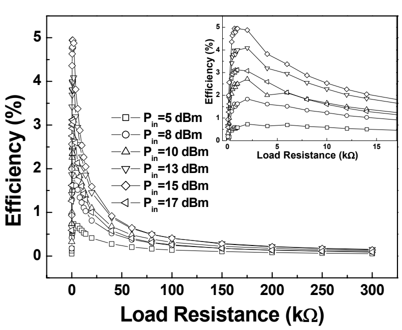

Fig. 11 Rectifier RF-to-DC conversion efficiency for different input power and load.

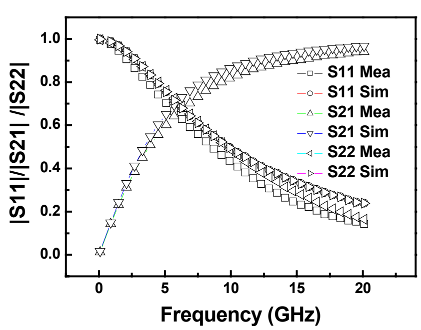

Fig. 12 Simulated and measured S-parameter up to 20GHz.

Table-1 Schottky Diode Main Parameters

I_S (A)	R_S(Ω)	V_D (V)	Φ_B (eV)	C_{JO} (fF)	n	M	V_B (V)
4.1e-14	73	0.55	0.628	178	1.12	0.2	9.0