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Robust, versatile, direct low-frequency noise characterization method for material/process quality control using cross-shaped 4-terminal devices

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Abstract

Low frequency (LF) noise measurement is a very sensitive tool for device quality and reliability monitoring. Despite of its potential interest, there are up to now relatively few LF noise studies combined and compared to standard reliability/quality analysis. One of the reasons is the difficulty to implement LF noise measurement on automatic wafer level testing. In this paper we promote a method using cross shaped 4 terminal devices (Hall crosses). The implementation of this method and its advantages over conventional noise measurement methods are described. This method, compatible with on-wafer probe testing, is of particular interest for material/processes quality control purposes especially for less mature material such as AlGaN/GaN Heterostructures.

1. Purpose of the work

Low frequency noise (or "excess noise") is in principle very efficient and sensitive for revealing electrically active defects in semiconductor devices. LF noise is also affected by degradation mechanism and process quality. It has been observed, in some cases, that devices showing higher excess noise are less reliable and have shorter lifetime [1, 2]. Therefore, it would be very tempting to routinely use noise measurements for quality control as well as for characterization of aging processes and reliability in semiconductor devices [2].

However, such a technique is not widely used in a production environment, partly due to the difficulty of performing on-wafer noise measurements [3]. Indeed, fluctuations known as "noise" are small as compared to the common-mode potential drop in a biased device. In order to suppress the deterministic common mode voltage due to biasing, it is customary to use either a Wheatstone bridge (differential measurement) or a dedicated electronic circuitry (single-ended measurement). In both cases, the determination of the true noise spectrum is not straightforward, due to both intrinsic and extrinsic reasons detailed below.

We describe here the use of cross-shaped 4-terminal devices (Hall crosses) when investigating for LF noise sources in planar technology such as Field-Effect-Transistors III-V or AlGaN/GaN based HEMT and SiC MESFET. We show that most of common measurement problems encountered with conventional 2-terminal (2T) noise measurements can be alleviated by biasing a 4-terminal (4T) device with the adequate shape between two opposite terminals and measuring noise perpendicular to the channel. Moreover, the physical interpretation of the noise spectra is more straightforward.

2. Noise Measurement using Cross-Shaped Devices

Standard noise measurement methods involve either a Wheatstone bridge configuration (Fig.1a) or a purposely designed electronic stage (Fig. 1b). In the present method (Fig. 1c), a cross-shaped symmetrical 4-terminal device is connected to a commercial current or voltage source and the transverse voltage whose output is fed to a FFT analyzer as shown in Fig. 2.

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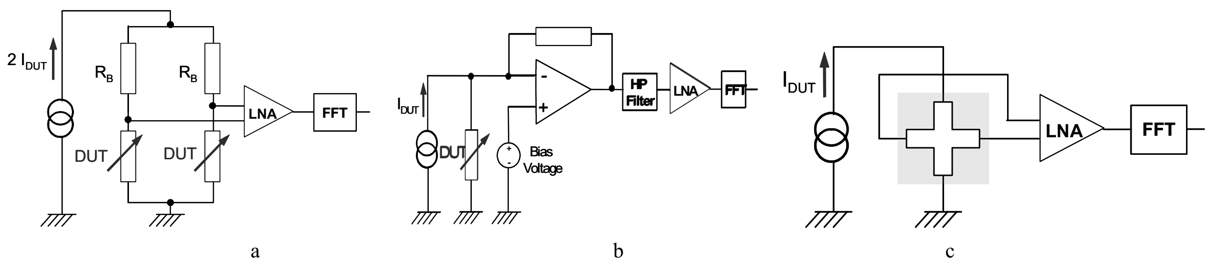

Fig. 1. (a) and (b): Standard noise measurement methods. (a) Differential measurement of the noise PSD of a 2-terminal device in a Wheatstone bridge configuration. (b) Single-ended measurement of the noise PSD of a 2-terminal device using a dedicated electronic circuitry. (c) The present differential noise measurement method using a four-terminal device.

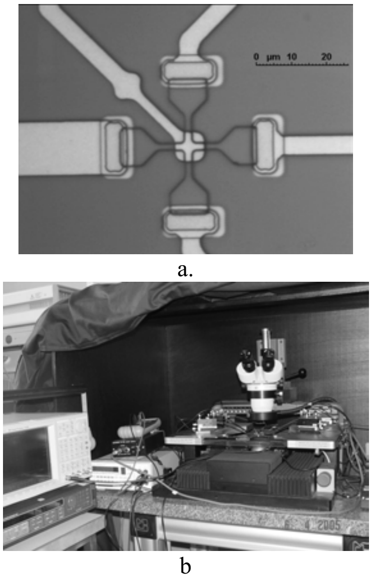

Fig. 2. Experimental set-up: a cross-shaped symmetrical 4-terminal device (a) is connected in the probe tester (b) to a Keithley 236 current source. The transverse voltage is amplified by a LI75-A very low noise amplifier, whose output is fed into an Ono Sokki CF5220 Fast Fourier Transform analyzer.

The 4-terminal (4T) method is characterized by the following features:

1. The observed noise originates from a small, well defined region of the channel at the intersection of the cross [4]. This brings two advantages:

- One gets access to the direct noise spectrum of the channel, without any need for de-embedding from series resistance of access regions, nor parasitic contribution of contact noise or access region noise.
- The noise is measured under well defined potential conditions, i.e. without spreading of emission activation energies that would be caused by the voltage drop in the channel.

2. A Hall cross is by itself an intrinsic, quasi-perfectly balanced differential bridge, with following advantages:

- The noise of the biasing source is fully rejected, since it is common mode. There is no need for a battery powered or extremely low-noise bias.
- It remains perfectly balanced when applying a gate or substrate voltage, or varying the temperature.

3. In addition, the area of the measurement loop can be made extremely small, in contrary to the case of a Wheatstone bridge using external resistors.

This makes the measurement much less sensitive to electromagnetic perturbations (external noise) [5].

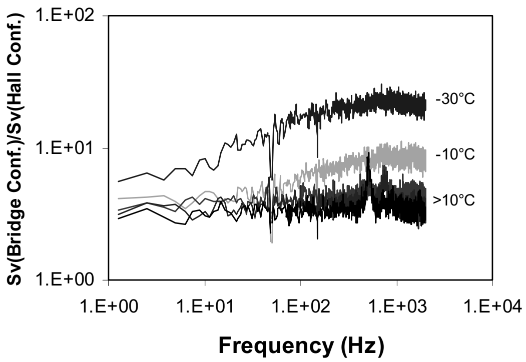

Fig. 3. Ratio of the noise PSD (Sv) of the same given device measured in the 2-T and 4-T configurations. An additional noise contribution from the ohmic contact region perturbs the noise spectrum at low temperature in the 2-T, but not in the cross configuration, thus permitting its assessment to contacts.

The design constraints relevant for noise investigations in the 4-T configuration are very generally the same as for any 4-wire measurement, i.e. that parasitic conduction in the voltage probe contacts has to be avoided. As a rule of thumb, for a Greek cross the aspect ratio L/W should be equal to at least 4 [6]. The LF power spectrum density (PSD)