Noise Measurement of Optoelectronic Coupled Devices for Reliability Screening: Is There an Optimal Threshold?

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Abstract. It is very useful to describe the methodology and also the judging rules, which enable us to predict the individual quality of electronic components, based on measurements of their noise. However, the published literature on screening standards, especially on how to draw an optimal threshold value to distinguish good quality from poor quality, are quite few. In this paper a screening approach for OCDs is proposed. The experimental results will be discussed in details.

INTRODUCTION

Noise as a diagnostic tool for quality control and reliability estimation of semiconductor devices has been widely accepted and used, and there are some papers published in this area [1-5]. It has been shown that experimental facts about noise help us to better understand the correlation between noise in a device and its reliability. Besides, life tests and aging tests have shown that both the initial noise and initial rate of noise increase correlates best with lifetime [6]. However, in most of the presented results there is a lack of a well defined criterion for quality validation of electronic components based on the noise generated by them. In [5] the classification rules of electronic components, based on their 1/f noise measurements are presented. The cases in which the method can be applicable are limited. Because of the classification rules based on 1/f noise only, it is not possible to meet high quality requirements, for in some cases there is a g-r noise or even burst noise in a semiconductor device, but its 1/f noise level, e.g. the noise measurement of OCDs, is as normal as other qualified devices.

From Fig. 1, it can be seen that a OCD is made of two parts: LED and Photodetector, both of which are P-N junction devices. Usually 1/f, g-r and burst noise

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are common noise existing in p-n junction. For this reason it is necessary that the generation mechanisms of 1/f noise, g-r noise and burst noise are all briefly discussed, especially on what kinds of defects can lead to these three kinds of noises. Also the relation between them should be studied. Then the screening threshold can be decided. Furthermore, the experimental results show that there does exist an optimal threshold.

1/f Noise Generation

Usually 1/f noise in a semiconductor device usually can be divided into fundamental 1/f noise and non-fundamental (or excess) 1/f noise [7]. The fundamental 1/f noise is connected with phenomena which are included in the process of the operation of the electronic component. It is believed that this 1/f noise has no relation to the semiconductor surface and the defects in the bulk [8].

The 1/f noise which is related to device defects is called non-fundamental 1/f noise, which means that this kind of 1/f noise is caused by device surface or bulk defects in most cases. Thus, it is possible for us to evaluate the device quality and reliability according to its magnitude. From this point of view, non-fundamental 1/f noise is of great value to device quality evaluation and reliability prediction. Most of the evidence suggests that in some types of device it is a surface effect, as in the case of a MOSFET where the semiconductor/oxide interface plays an important role, but in other devices, such as a homogeneous resistor, 1/f noise is thought to be a bulk effect associated with a random modulation of the resistance, implying a fluctuation in either the number or the mobility of the charge carriers. For example, [9] has shown that 1/f noise in a specimen with more dislocations is at least one order of magnitude larger than that of the specimen with fewer dislocations.

Different causes for 1/f noise generation have been reported as follows: (1) the fluctuation of surface recombination velocity in the p-n junction, (2) the fluctuation of trapping in the oxide layer in BJTs or in MOSFETs, (3) dislocation 1/f noise, (4) quantum 1/f noise (in dispute). It is obvious that 1/f noise intensity is related to the generation-recombination center (surface defect) numbers in device oxide layer. Thus, the establishment of a relationship between device surface quality and reliability can help us judge and screen devices according to excess noise intensity.

g-r Noise Generation

It is generally believed that g-r noise in a device has a direct relation to semiconductor defects (impurities, lattice dislocation etc.) Therefore, it has become an effective method of analyzing bulk defects and reliability screening by means of measuring g-r noise in devices.

It has been experimentally shown that the defects (dislocation, deep energy level impurities) in the emitter junction is the main sources of BJT g-r noise, especially as a p-n junction is in a forward biased state.

JFET g-r noise is produced in barrier trap and channel recombination centers. It can be caused by deep energy level impurity and lattice defects.

Thus, it has been known that measuring JFET g-r noise can be helpful to estimate device defects and reliability, especially on barrier defects. Moreover, deep energy level impurity and defects in the forbidden band can also be estimated.

Burst Noise Generation

Hsu [10] first presented a physical model explaining burst noise. In this model, it is thought that heavy metal impurities deposited in the charge region of the p-n junction results in burst noise.

But Blasquez [11] has found that so-called 'pure' lattice dislocations can also cause burst noise, even when heavy metal impurity deposits have been removed. Therefore it seems that metal impurity precipitates are not indispensable for the production of burst noise. Ref. [12] has given new explanation of the causes of burst noise. Burst noise in forward-biased junction is generally acknowledged nowadays to be due to defects in the vicinity of the junction. The precise nature of the defects is somewhat uncertain.

A number of experiments have already shown that metal lattice dislocation is the major sources of burst noise for both bipolar transistors and integrated circuits.

SCREENING CONDITIONS OF 1/F NOISE, G-R NOISE AND BURST NOISE

According to above analysis, it can be seen that 1/f noise is closely related to the surface states of the semiconductor device, g-r noise is relatived to device bulk defects such as impurity, dislocation etc., and burst noise is related to lattice dislocation. It should be pointed out that BJT emitter region edge dislocations make both 1/f noise and burst noise simultaneously increase in most cases.

It can be seen that an excess noise is closely associated with some defects in the devices and/or imperfections of technology. So through noise measurement, their noise amplitudes can be used to indicate the presence of defects. A device with burst noise can be found from instantaneous time-domain waveforms and g-r noise can be found through noise spectral component analysis. In this paper, the ratio of noise value at 10 Hz to noise value at 1 Hz is used to judge whether there is g-r noise or not. Therefore, an optimal threshold value is needed to reject a device with burst noise, excess g-r noise and excess 1/f noise, which may result in potential failures.

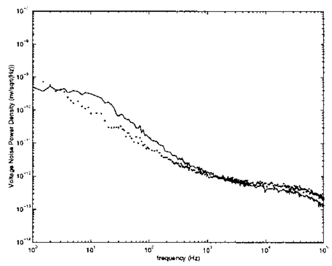

FIGURE 1. Curves of PSD of device #131 with g-r noise and device #12 without g-r noise

From the generation mechanisms of 1/f, g-r and burst noise, it can be seen that the probability to generate these three type noise by the same defect is quite small although some defects may cause two kinds of noise simultaneously in some cases. Therefore it is necessary that there be three different screening conditions to meet the requirement of high reliability, if the devices with excess 1/f, g-r or burst noise need to be rejected. In this paper the screening conditions proposed are; (a) V_n(1 Hz)$\geq$80000 nV/$\sqrt{\text{Hz}}$ (b) V_n(10 Hz)/V_n(1 Hz)$\geq$0.6 (c) any amount of burst noise.

EXPERIMENTAL RESULTS

A device will be rejected if it meets any one of the three screening conditions. First, the condition (a) is used to reject the device with excess 1/f noise and the value, 80000 nV/$\sqrt{\text{Hz}}$, is a statistical value for 500 OCDs (GO 103, Shuzhou Semiconductor) measured results.

Condition (b) is used to reject a device with g-r noise, for we have found in most cases that the noise power spectrum of the device with g-r noise is usually shown in a plateau from 1 Hz to 10 Hz, by experiment. Therefore, the ratio of V_n(10 Hz) to V_n(1Hz) is chosen as a judging threshold to discern whether there is a g-r noise or not – as this ratio is quite different if the device is without g-r noise. An example is shown in Figure 1.

In fact it is possible that the g-r noise does not appear in this frequency region, i.e. it is present in another frequency range. Then, curve fitting methods may be used to analyze whether there is a g-r noise or not. The details can be seen in [4].

Condition (c) implies that a device with burst noise should always be rejected, in most cases, because it can not only affect device reliability, but also hinder normal device operation, especially in digital circuits, leading to malfunction.

In our experiments, it was found that 51 specimens should be rejected. Among them, 19 samples are with excess 1/f noise, 18 with excess g-r noise and 14 with burst noise. However, only 4 samples met conditions (a), (b) and (c) simultaneously. In other words, there were 15 samples with excess 1/f noise and low g-r noise, 14 samples with low 1/f noise but with excess g-r noise, and 10 samples with low 1/f

TABLE 1. Failure rate and statistical experimental results of 500 specimens

Cond.	With excess 1/f g-r, burst noise	With small 1/f g-r,burst noise	λ_1	λ_2	r	Estimated error
(a,b,c)	51	449	60.8%	3.56%	17.1	7.84%
(1)	84	416	36.9%	3.85%	9.58	44.1%
(2)	31	469	100%	3.41%	29.4	51.6%

noise and g-r noise but with burst noise. Hence to improve the reliability of OCDs, using 1/f, g-r and burst noise together, as a screening standard, to exclude devices which may have surface and bulk defects, is indispensable.

DISCUSSION OF THE SCREENING CRITERION

For 500 GO103 optoelectronic coupled devices, several parameters were measured before and after a reliability test of 1000 h. The conditions of the reliability power test were $I_F = 10$ mA, $V_{ce} = 10$ V, temperature=23 °C and r.h.=50%. The criterion for failure of OCDs are $|\Delta CTR/CTR| > 30\%$, $I_R > 50$ μA, $R_{iso} < 10^9$, $V_{iso} < 500$ V, $C_{iso} > 1$ pF, $I_{CEO} > 0.1$ μA and $V_R < 5$ V. After the reliability power test, 47 OCDs were found to have failed, in which 31 were with excess 1/f, g-r or burst noise, and 16 with small 1/f, g-r and burst noise.

If the noise threshold levels used as a noise criterion are selected as condition (a), (b) and (c), then the estimation error is 4/51=7.84%. If condition (a) and (b) are changed into 70000 and 0.5 (which means that high reliability is required) – let us call this condition (1) – then 84 OCDs will be rejected with excess 1/f, g-r or burst noise and the estimated error is 37/84=44.1%. Contrary to this case, if the conditions (a) and (b) are changed to 90000 and 0.7 (which means that lower reliability is required) – let us call this condition (2) – then there are 31 OCDs rejected with excess 1/f, g-r or burst noise. The estimation error is 16/31=51.61%.

For a large number of OCDs, a correlation should exist between failure rate and noise level, i.e. devices which have excess noise should have a large failure rate λ_1 (λ_1 is the number of failed devices which have excess noise, divided by the total number of all devices which have excess noise). The devices that have non-excess noise should have a small failure rate λ_2 (λ_2 is the number of failed devices which have non-excess noise, divided by the total number of devices which have non-excess noise) [13]. Therefore, the ratio of the failure rates is defined as $r=\lambda_1/\lambda_2$ and the results are shown in Table 1.

According to Table 1, it can be seen that the correct way to get the optimal threshold is by considering estimated error and maximum failure r together. This means that the optimal noise criterion of [13], which only considers the maximum value of r is insufficient. It has shown by experiment, here, that our screening method, three conditions (a), (b) and (c) are used to reject OCDs with excess 1/f noise, g-r noise or burst noise, is necessary and reasonable.

CONCLUSIONS AND OPEN QUESTIONS

On the basis of experimental results, the conclusions are:

(1) It is emphasized that all of noise generation mechanisms should be studied, rather than one type of noise at only one specific frequency, for reliability estimation of OCDs. It is found that 1/f, g-r and burst noise must be used as three independent criteria for reliability estimation. Also the optimal noise threshold levels should be found for both minimum error and the maximum value of failure rate r.

(2) The experimental results show that, after a lifetest, not all rejected devices initially exhibit an excess low frequency noise. However, the results have demonstrated that the failure rate for devices, which initially exhibit high noise, is about 10 times higher than the failure rate of devices which initially exhibit low noise.

There are several problems which need to be addressed, to improve prediction accuracy and screening method, in order to get an optimal screening threshold.

(a) An complete analysis of intrinsic noise sources in a semiconductor device.

(b) The link between typical defects and noise sources should be established.

(c) There are some devices whose noise values are quite normal when initial tests are carried out. However, after an aging test they are already in early failure and should be rejected. Is there any hidden defect in such devices?

(d) Furthermore, we should try to use the the measured noise value to find the defect location and the reason of defects generated.

(e) A further advance would be a reasonable prediction of device life expectancy, on the basis of excess noise analysis.

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