Full Paper

TECHNIQUE FOR AUTOMATING DC RELIABILITY MEASUREMENT OF MULTIPLE METAL-INSULATOR-METAL (MIM) RECTIFIERS

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ABSTRACT

An automatic biasing device for characterizing metal-insulator-metal (MIM) rectifiers is presented. The device shows a novel investigational and direct current test approach on MIM rectifiers, where tests are performed on multiple diodes for weeks at the same time, automatically, at specified time intervals and the raw data is saved for further analysis. The developed automatic biasing device makes it easy to determine the nature of the MIM diodes' rectified current. The developed remote biasing device can also be used for effectively current-stressing multiple MIM diodes, making it a very versatile DC characterization device. Furthermore, the developed method was used to characterize the effect of epoxy encapsulation on the performance of MIM rectifiers with results comparable to the state-of-the-art.

Keywords: *Metal-insulator-metal (MIM) rectifier, current-stressing, biasing, Mbed, microcontroller, I-V curve*

1. INTRODUCTION

Metal-insulator-metal (MIM) rectifier typically comprises of 2 metals films segregated by a thin dielectric film – typically a few manometers, is an ultra-fast rectifier with a variety of applications, such as the rectifying of high-frequency signals, infrared cameras, terahertz radiation sensing, frequency mixers, radio frequency identification (RFID), and the harvesting of thermal energy (Drullinger et al. (1983); Siemsen & Riccius (1984); Pan et al. (2014)). The MIM diode has recently been realized by means of a novel cheap method whereby the insulating film comprises octadecyltrichlorosilane (OTS) (Etor et al. (2016)), which is a self-assembled monolayer (SAM) typically utilized to functionalize the surfaces of silicon dioxide (SiO_2), and in the form of a thin layer has a thickness of nearly exactly 2 nm (Jung & Choi (2009); Kim et al. (2008)). The OTS was coated on the surface of titanium (Ti), between the Ti and platinum (Pt) metal layers, giving rise to a high nonlinear *I-V* curve due to the work function variation of 1.4 eV between Ti and Pt. Upon performing dc tests on the diodes over a period of three days after manufacture, the rectified current of the diodes was found to be decreasing, which is a common issue with MIM junctions (Choi et al. 2011). The graph in Figure 1 below depicts an OTS MIM rectifier current degradation curve.

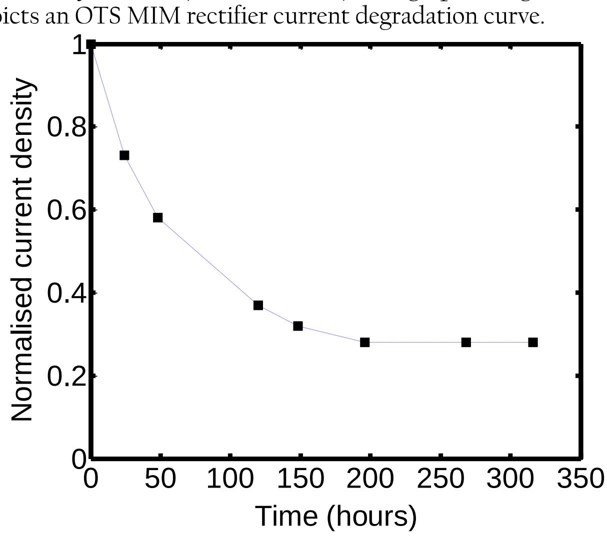

Figure 1: Current degradation curve of the OTS MIM rectifier.

The atmosphere (H_2O vapour and O_2) permeating the MIM junction and oxidizing the Ti film is believed to be a significant cause of the rectified current degradation. In order to investigate this hypothesis and determine the rectifiers' life span in relation to time and current stressing, *I-V* characterization was performed on two sets of these diodes, with each set fabricated on separate wafers; one set was encapsulated, while the other was left under normal atmospheric conditions. The *I-V* characterization was then performed on the diodes on the different wafers repeatedly, at the same times for a particular overall period. An automated apparatus that is able to bias the rectifiers in specified interregnum was required in order to carry out *I-V* measurements on the fabricated encapsulated or sealed and the unencapsulated rectifiers at the same time over a lengthy period in a more regulated way.

This work describes a novel technique for performing this type of characterization, where to bias the rectifiers automatically, an Mbed microcontroller with a digital to analogue converter (DAC) and numerous analogue to digital converters (ADC) coupled with a custom made probe station with pogo pins was employed.

2. DESCRIPTION OF MEASUREMENT SYSTEM

Several ADCs on the Mbed enable for simultaneous testing of various devices. The microcontroller was programmed with a C programming language that lets it produce a voltage that is sinusoidal to bias rectifiers. To lower the bias voltage to around ±0.25 V, an acceptable operating voltage range without causing irreversible damage to the OTS MIM rectifiers, a resistor with ten to fifteen times more resistance than that of the rectifiers was coupled between the rectifiers under test and the voltage being produced by the microcontroller. To prevent loading, buffers were coupled to the outputs of the Mbed. The device was supplied by a computer USB connection, and it automatically generated a sine waveform based on the written C program, biasing the connected rectifiers and therefore current-stressing them also on a periodic basis. For all the test runs, the *I-V* characteristics data was stored for subsequent studies. The schematic and image of the proposed Mbed-based automatic biasing apparatus are shown in Figures 2 and 3, respectively.

3. RESULTS AND DISCUSSION

Under the same processing parameters, new MIM diodes were manufactured on two distinct substrates (as in Etor et al.

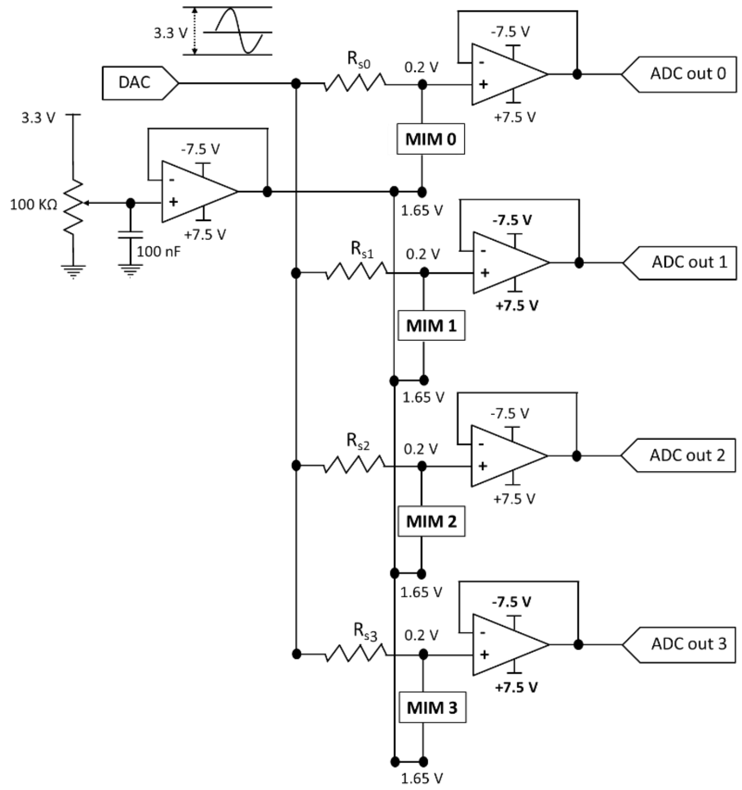

Figure 2: Schematic of the proposed automatic Mbed-based biasing device. This device measures the I-V characteristics of 4 MIM rectifiers at the same time.

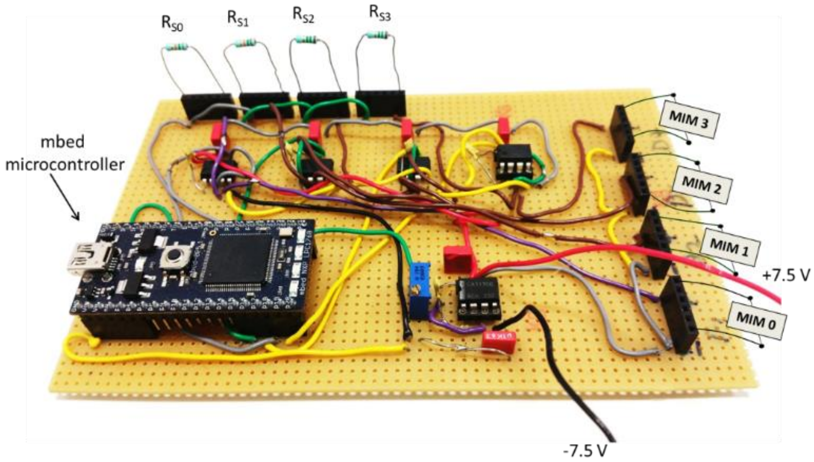

Figure 3: Image of the built proposed device (with the schematic shown in Figure 2 above).

(2016)) at the same time. One substrate was stored in a location with typical atmospheric parameters (values of temperature and humidity were 20 ºC and 48% respectively) as soon as the first round of I-V tests was completed. The other substrate was sealed in epoxy resin, which is commonly used to encase microelectromechanical systems (MEMS). The epoxy entirely covered the rectifiers' leads and junctions, leaving, however, the contact pads of the rectifiers exposed for electrical characterization to take place.

The built Mbed-based biasing apparatus was then utilized to automatically test the rectifiers' *I-V* behaviour, once every hour, for 3 weeks, extracting and recording the raw *I-V* data for each run. Figure 4 shows the set up for the measurement.

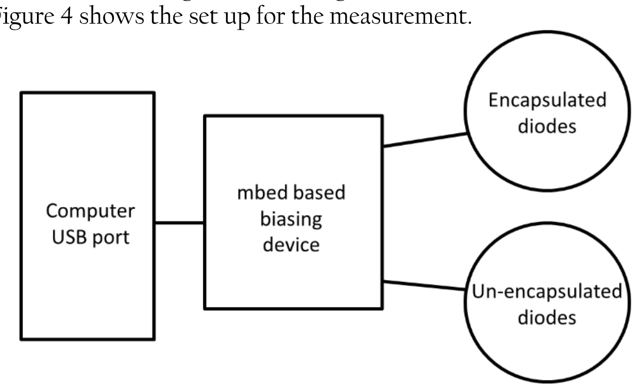

Figure 4: Set up for the I-V characteristics tests.

The unencapsulated and the sealed rectifiers' *I-V* characteristics are shown by the graph in Figure 5(a) and 5(b), respectively, with 504 *I-V* curves in each graph – one curve per hour for 3 weeks. As illustrated in Figure 5(a), the unencapsulated rectifiers' rectified current decreased by around 80% between the first and last *I-V* tests in this 3 weeks period.

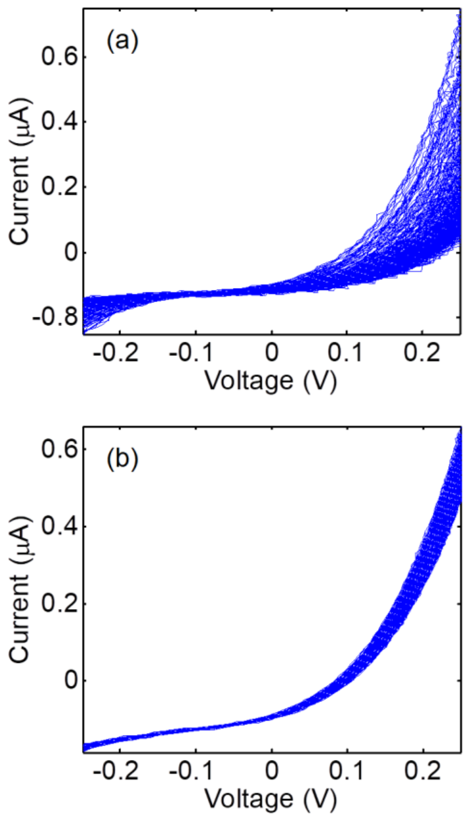

Figure 5: (a) The I-V curve of the unencapsulated and (b) the sealed rectifiers.

Early in the measurements, the large variation between the first and last few *I-V* curves for the unencapsulated rectifiers, shown in Figure 5(a), verifies that these rectifiers' current drops rapidly in the early period after they have been manufactured, and then stabilizes. This discovery was found to be in agreement with the preliminary tests carried out to determine the nature of the rectifiers' current time-dependent degradation, as described in (Etor et al. (2016)). In contrast, the rectified current of the sealed rectifiers, shown in Figure 5(b), only decreased by around 25% for the whole period that the experiment was conducted. The around 25% current reduction is mostly due to the rectifiers being current-stressed during the experiment, which is another function that the built automatic biasing device can clearly perform in an effective manner. Figures 6(a) and 6(b) shows the zero bias curvature coefficient (CC_{ZB}) of the unencapsulated and sealed rectifiers, respectively. Curvature coefficient, CC, is a figure of merit that affects rectified current in MIM rectifiers. It is a measure of the non-linearity of the rectifier *I-V* curve at a given point, expressed in Equation (1) (Etor et al. (2016)). The CC can be calculated at any desired voltage but is more useful at zero bias especially for applications such as energy recovery or detection where there would not be biasing when in operation.

$$CC = N_L R_v|_{V=V_g} \tag{1}$$

where N_L is the non-linearity of the rectifier at a given voltage V_g, as expressed in Equation (2).

$$N_L = \frac{d^2I}{dV^2}\bigg|_{V=V_g} \tag{2}$$

and R the rectifier resistance at a given voltage V_g, defined by Equation (3).

$$R = \left(\frac{dI}{dV}\right)^{-1}\bigg|_{V=V_g} \tag{3}$$

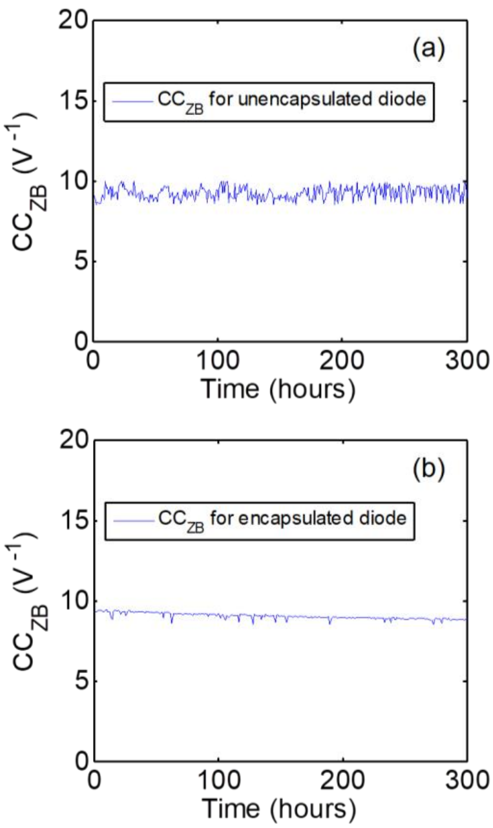

Figure 6: (a) CC_{ZB} plot of the unencapsulation and (b) sealed rectifiers.

The parameters stated above can be obtained directly via electrical measurement or from polynomial fitting to the rectifier *I-V* curve raw results. The zero bias curvature coefficients (CC_{ZB}) shown in Figures 6(a) and 6(b) are obtained directly from the MIM rectifiers *I-V* curve results.

As can be seen in Figure 6, the CC_{ZB} of the un-encapsulated diode is very irregular and noisy when compared with the CC_{ZB} of the encapsulated diode. This is expected and shows that the encapsulation method employed works effectively.

4. CONCLUSION

An automatic Mbed microcontroller based biasing device for MIM rectifiers have been developed. The device shows a new investigational and direct current test approach on MIM rectifiers. Because the MIM rectifier is impacted by the weather, giving rise to deteriorated rectified current, the created automatic biasing device makes it simple to ascertain the nature and pattern of the rectifier's current deterioration and to assess the effectiveness of any encapsulation method used to avoid current degradation. The developed biasing device can also be used for effectively current-stressing multiple MIM diodes, making it a very versatile DC characterization apparatus for researchers.

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