Impact of sidewalls on electrical characterization

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Abstract— **In this article the impact of sidewalls, formed during reactive ion etching, on the electrical behavior of thin film structures is presented. The presence of sidewalls was experimentally characterized by sheet resistance measurements on Van der Pauw structures. The effect of these sidewalls on the extraction of specific contact resistance from Cross Bridge Kelvin Resistance (CBKR) structures is discussed.**

Index Terms— **Van der Pauw, phase change material, side walls, CBKR structures, contact resistance.**

I. Introduction

Pattern transfer is one of the essential steps in microelectronic processing. This is achieved by etching of the layers using a protective mask. Reactive Ion Etching (RIE), which is a combination of the physical sputtering and chemical etching in plasma, is the preferred etching process for achieving anisotropic etching profiles. The strong directional nature of the incident ions from physical sputtering allows removal of the layer in a highly anisotropic manner. At a low chemical etching component, however, the sputtering mechanism may lead to the re-deposition of layer material on the sidewalls of the protective mask. These sidewalls can remain attached to the etched layer even after removal of the mask.

In this article, the presence of sidewalls is characterized by four point Current-Voltage (I-V) measurements on thin film Van der Pauw structures. For a square Van der Pauw test structures, the measured electrical resistance ($R = V/I$) is independent of the dimensions of the square [1]. The sheet resistance (R_{sh}) is obtained using the geometrical factor $\pi/\ln(2)$, i.e. $R_{sh} = R \times 4.53$. It is in turn related to the resistivity of the material (ρ) and the thickness (t) of the layer by:

$$R_{sh} = \frac{\rho}{t} \qquad \text{equ (1)}$$

II. Test Structures

Thin film Van der Pauw structures of 2, 5, 10, 20 and 50 μm square were processed from phase change material (PCM) and Titanium Nitride (TiN) to characterize the presence of sidewalls. PCM and TiN layers with a thickness of 20 *nm* and 50 *nm* respectively were deposited by rf magnetron sputtering on $Si\text{-}SiO_2$ substrate. An 800 *nm* thick SPR resist mask is used to define PCM and TiN Van der Pauw structures. The TiN layer is patterned by RIE in a chlorine-based chemistry with a chamber pressure of 60 mTorr. The chemical nature of etching for TiN resulted in no sidewalls. Due to the high chemical reactivity of PCM, it was etched in argon plasma with sputtering as the dominant etching mechanism. Re-sputtering leads to the formation of PCM sidewalls on all four sides of the Van der Pauw squares, due to deposition of PCM on to the vertical faces of the masking layer. The height of sidewalls formed is approximately 1 μm which is similar to the thickness of the mask. The masking resist layer is then removed in oxygen plasma. The structure is then covered with a 500 nm passivation oxide, through which contacts are opened for electrical measurements. The presence of sidewalls in the PCM layer also resulted in bad coverage of the passivation oxide layer over the structures. Scanning Electron Microscopy (SEM) inspection and four point I-V measurements were performed to characterize the presence of sidewalls on these Van der Pauw structures.

Fig 1(a) shows a SEM image of sidewalls after mask removal, and 1(b) shows the bad coverage of the oxide passivation after complete processing.

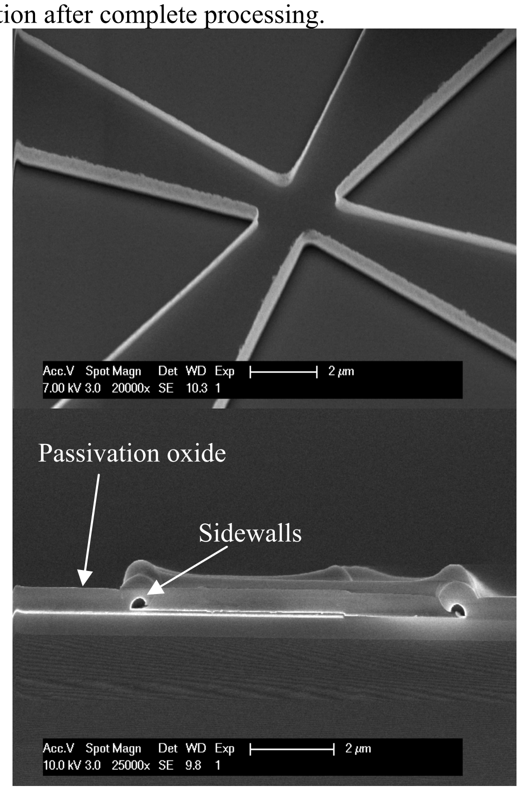

Figure1: Standing sidewalls formed due to re-deposition; (a) after resist removal, (b) bad coverage of passivation layer after complete processing

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III. EXPERIMENTAL RESULTS

Sheet resistance measurements were performed on PCM and TiN Van der Pauw structures to electrically characterize the presence of sidewalls. The symmetry of the structures was examined by measuring these structures in four different directions rotated by 90° each. The results are shown in Fig 2.

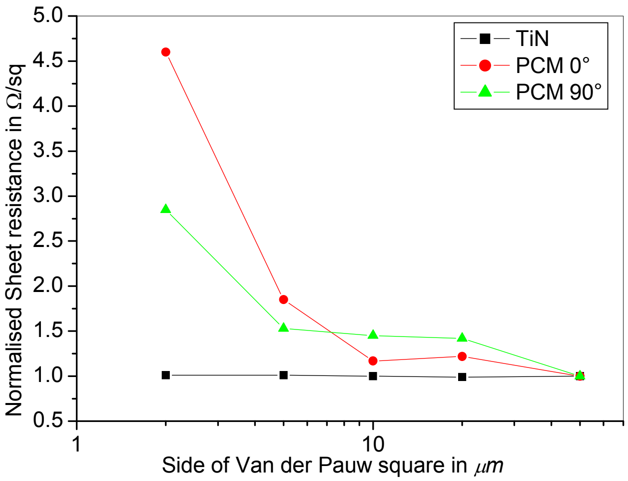

Figure 2: Sheet resistance measurements on PCM Van der Pauw structures with standing sidewalls, measured in two different directions with 90° rotation. The normalized TiN results (no sidewalls) are shown for reference.

The sheet resistance increases when the dimension of the Van der Pauw square decreases. By first approximation the sidewalls expand the Van der Pauw square equally on all the sides. The resulting final structure will also be a square but, since the sidewalls are formed by re-sputtering of material, which will have a different density than the layer itself, the resistivity (ρ) will be higher. Also the thickness (t) will be less than the PCM thickness. This means that the effective sheet resistance (equ 1) of the sidewalls will be significantly higher. However, if the resistivity of the sidewalls is orders of magnitude higher, the effect of the sidewalls will not be observed in the measured resistance values. The measured sheet resistance for the smaller squares is higher as the contribution of the effective sheet resistance of the sidewall increases for the smaller structures. In practice the sidewalls do not exhibit a regular shape around the squares: they may also split or fall down locally with or without breaking (electrical) connections. As opposed to this in the case when the sidewalls are fallen on to the layer itself after mask removal, the layer thickness increase and so the sheet resistance decreases for the smaller squares. This means that, due to these non-homogeneities, the squares can also become electrically asymmetric and this will be more pronounced for the smaller squares. Indeed, the measurements in two different directions show a larger offset for the smaller squares (Fig 2).

IV. DISCUSSIONS

Processing of the test structures to measure the electrical contact resistance of metal-PCM contacts requires patterning of the PCM layers by RIE. CBKR structures are commonly used test structures for contact resistance measurements and extraction of specific contact resistance (ρ_c) [2]. The layout of a CBKR structure with metal-PCM contact area ($A = L \times L$) and overlap length (δ) is shown in Fig 3.

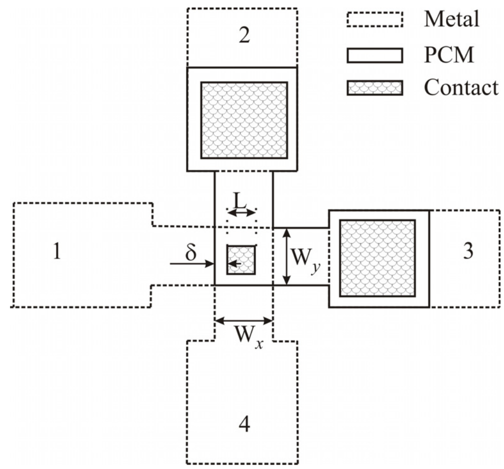

Figure 3: Cross Bridge Kelvin Resistor structure showing upper (PCM) layer, lower (metal) layer and the contact structure (δ, L)

The measured resistance (R_k) of the CBKR structure includes two parts: the resistance of the contact (R_c), and the resistance of the overlap area (R_d). To accurately extract ρ_c the resistance contribution of the overlap area R_d needs to be eliminated from the measured resistance. This is done using the 2D approximation of the contact area [3]:

$$R_k = \frac{\rho_c}{A} + \frac{4R_{sh}\delta^2}{3W_xW_y}\left[1 + \frac{\delta}{2(W_x - \delta)}\right] = R_c + R_d \qquad \text{equ (2)}$$

The resistance of the overlap area includes the sheet resistance of the layer, which is measured from accompanying Van der Pauw structures. Any variation in the sheet resistance due to the presence of sidewalls will directly result in an inaccurate extraction of the specific contact resistance from the CBKR structures. Also the presence of sidewalls in the CBKR structures itself will result in an inaccurate determination of the overlap δ and sheet resistance R_{sh}.

V. CONCLUSIONS

Van der Pauw structures can successfully be employed to electrically characterize the presence of sidewalls that were formed during RIE etching. These formed sidewalls may stand vertically or fall down, with or without breaking (electrical) connections. The formation of standing side walls can lead to significant higher values and spread in the sheet resistance of Van der Pauw structures, particularly for the smaller ones. This leads to an underestimation of the extracted specific contact resistance from CBKR structures using these R_{sh} values in the 2D approximation (equ 2). Moreover side walls may lead to an inaccurate estimation of the overlap length in CBKR structures (equ 2).

VI. ACKNOWLEDGMENTS

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