Porosity Analysis of Porous Copper Films using Scanning Acoustic Microscopy and 3D SEM/FIB Tomography

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1. Introduction

Moore´s law and More than Moore [1] drive the trend in the semiconductor industry. Both trends lead to enhanced device performance but also trigger challenges with respect to the materials in use [2,3]. Significant impact on device functionality and reliability results and eventually will lead to the breakdown of the device. A possibility to keep the trend going is the use of novel material concepts. Porous materials might show in this context possibilities with respect to performance and miniaturization. Since the pore parameters such as porosity, etc. can be linked e.g. to the mechanical or thermal behaviour, the understanding of those parameters is highly important. Novel characterization workflows should help to establish improved design guidelines and enhance reliability. Nevertheless, there are certain challenges to quantify porosity accurately, as fast as possible, and non-destructively. Usually more advanced microscopy approaches with respect to 3D imaging and data analysis are necessary for accurate analysis. However, in-line inspection tool with faster processing time and integration capabilities would be highly beneficial for industrial applications.

Scanning electron focused ion beam nano-tomography (nano-FIB tomography) [4] and micro-X-ray computed tomography (μ-XCT) [5] represent image based characterization methods, which are suitable to characterize 3D porosity in lab environment. Nano-FIB tomography, a destructive method, shows high resolution and contrast but long FIB slicing times (about 10h) for a relatively small 3D volume of interest (VOI). On the other hand, μ-XCT represents a non-destructive experimental method and does not need sophisticated sample preparation. However, possible disadvantages of the μ-XCT are the possible resolution and contrast. which are mainly determined by the focal spot size, sample material, target, and detector.

Scanning acoustic microscopy (SAM) represents a non-destructive characterization method which is in particularly highly used for the detection of delaminations, voids, or inclusions in microelectronics. Scanning modes like the A-scan or C-scan are used to qualitatively determine the size-related features. In general, acoustic waves are mechanical waves which interact with the mechnical properties of the medium. Acoustic waves show the ability to provide information about elastic related material properties. However, the use of this information remains largely unused in acoustic microscopy.

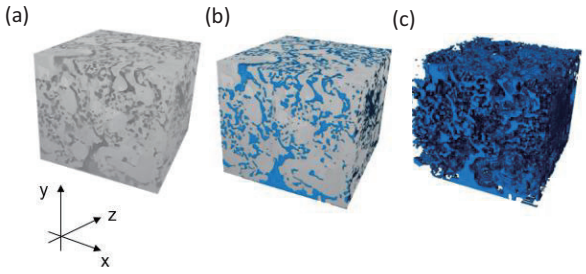

Fig. 1 Nano-FIB tomography results of the porous copper film. (a) Un-segmented porous copper film with copper (light grey) and pores (dark grey). (b) segmented pore space (blue) and copper matrix (light grey). (c) Segmented pore space (blue).

In this paper, we investigate the use of scanning acoustic microscopy to characterize the porosity of sintered porous copper (Cu) films on an Si(100) substrate. Therefore, we excite surface acoustic waves (SAWs) and detect specific interference patterns on the sample surface generated by the interaction of the SAWs with the pores. We evaluate the material specific Rayleigh velocity and combine the SAM data with the porosity data obtained from nano-FIB tomography.

2. Material

We use six porous copper foils. The foils are fabricated using stencil printing. The copper is deposited on Si(100) and processed at elevated temperatures and in a controlled atmosphere. By adjusting the process parameters such as print pressure and speed, gas flow, ramp rates, plateau temperatures, etc., six copper foils with different porosities and pore morphologies are produced. The thickness of these foils is up to about 30 μm.

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2. Methods

We use a cross-beam scanning electron microscope from Zeiss (AURIGA® - CrossBeam workstation) to perform the 3D imaging of the porous copper films. The reconstructed volume of interest (VOI) is about 10 µm x 10 µm x 10 µm. The vertical face of the cube is milled with the ion beam. The SEM image was taken at an 54° angle by a SESI detector. We reconstruct the 3D dataset with Avizo. We use a image analysis workflow [6] to extract the porosity.

For the acoustic investigations, we use a SAM 400 (PVA, Analytical Systems GmbH, Westhausen, Germany) in reflection mode. We use a transducer with a nominal center frequency of 100 MHz. The lens of the transducer shows an opening angle of 60°, which is larger than the Rayleigh angle of the copper (~46°). If the distance from the transducer to the sample surface is smaller than the focal length of the transducer and the opening angle of the transducer is exceeding the critical Rayleigh angle, surface acoustic waves (SAWs) can be excited on the sample surface and leak back to the lens.

3. Results

We use an SAM to detect the porosity in copper films based on the SAW excitation and the interaction of the SAWs with the pores. We combine the SAM with nano-SEM FIB tomography.

In **Fig. 1** we show an example of a 3D reconstructed image of a porous copper thin film. Figure 1(a) shows the unsegmented porous copper film whereas Fig. 1(b) and 1(c) illustrates the segmented pore space with and without the copper matrix, respectively. The segmented data was used to extract the porosity, which is defined by the fraction of the void volume over the total volume of interest.

In **Table 1** we show the results of the evaluated porosity from the 3D FIB image data (Por_{FIB}) and SAM data (Por_{SAM}) as well as the Rayleigh velocity v_R. We use the interference fringes generated at the pores to evaluate the distance $\Delta l_{fringes}$ (**Fig.2**). For every sample, we measured the distance $\Delta l_{fringes}$ for 10 different locations on the sample. We used for the evaluation the equation $v_R = v_{R0}(1-Por)^k$ with $v_{R0} = 2020$ m/s for bulk copper and k = 0.25.

4. Conclusion

The porosity obtained from the SAM measurements corresponds very well to the results obtained from the nano-FIB tomography. The results demonstrates that SAM as a non-destructive method might be highly suitable for process attendant pore characterization.

sample	v_R (m/s)	Por_{SAM}	Por_{FIB}
1	1838	0.34	0.31
2	1801	0.42	0.37
3	1717	0.45	0.48
4	1702	0.41	0.50
5	1695	0.42	0.50
6	1624	0.61	0.58

Table 1. Porosity obtained from SAM (Por_{SAM}) and nano-FIB tomography (Por_{FIB}) as well as the evaluated Rayleigh velocity v_R.

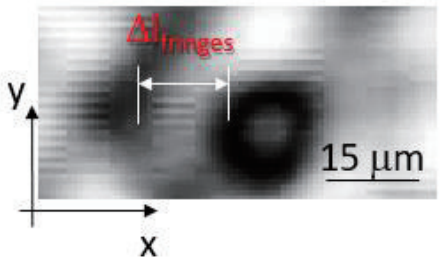

Fig. 2. C-scan SAM image showing the resulting interference fringes generated at the vicinity of a pore due to the excitation of SAWs. The distance $\Delta l_{fringes}$ between adjacent minima (black) of two interference fringes is used to evaluate the porosity.

3. References

1. W. Arden, "More than Moore White Paper," International Roadmap for Semiconductor ITRS, (2010).
2. R. Treml, *et al.* Acta Materialia, 103, 616-623, 15 (2016).
3. J. Broughton, *et al.* Journal of Electronic Packaging, 140, 4, (2018).
4. E. Widiatmoko, *et al.* The third nanoscience and nanotechnology symposium, 23-26, (2010).
5. D. Wildenschild and A. Sheppard, Advances in Water Resources, 217-246, 51, (2013).
6. A. Wijaya et al. (submitted).

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