Electroplating of Aluminum using Ionic Liquids for Bonding, Via and RDL applications

Silvia Braun[a,*], Imants Cirulis[a], Maik Wiemer[a], Stefan Schulz[a,b]

[a] *Fraunhofer Institute for electronic nano systems (ENAS), Technologie Campus 3, Chemnitz, 09126, Germany*
[b] *University of Technology Chemnitz, Center for Microtechnologies Reichenhainer Str. 70, Chemnitz, 09126, Germany*

Aluminum is often used in semiconductor fabrication due to material and processing properties as well as the CMOS compatibility. Al layers are used as electrical traces, contact pads or passivation material. However, the usage of Al layers thicker than 4 µm is limited. Even though, high-rate sputtering is available and can be used for relatively thick Al layers in range of 10 to 20 µm, the patterning of full area deposited thick Al layers is challenging and causes problems in line-space ratios. For other typical metals, like copper, gold or nickel, electroplating is used to achieve thick and patterned layers by depositing through a resist mask, also called pattern plating. For those metals, water-based electrolytes are used. The electroplating of Al can not take place in water-based electrolytes due to its negative standard potential of E_0=-1.67 V. The water would decompose before a reduction of an Al species occur. Therefore, ionic liquids (ILs) are used for the electrodeposition of metals with highly negative standard potential. ILs are organic salts which can be liquid at room temperature. They offer a wide electrochemical window, low vapor pressure and low flammability. Thus, electroplating with ILs as solvent has gained significant attention in the last 35 years [1,2]. The deposition of Al is reported from different ILs for various application, like corrosion resistance [3,4], thermal and electrical conductivity [5,6] or batteries [7–9]. By introducing the electroplating of thick Al layers on wafer level, new application possibilities open up in the back-end fabrication especially system packaging [10].

The electroplating was developed on 150-mm wafer level from the IL 1-ethyl-3-methylimidazolium chloride (EMImCl) and aluminumtrichloride ($AlCl_3$) in a ratio of 1:1.5. The electroplating process was carried out in a plating unit, which was placed within a nitrogen filled glove box. The inert gas atmosphere protects the IL for moisture and their decomposition. The seed layer changed during the process development from gold to highly doped silicon to Al. The deposition of Al onto Al seed layer is important to achieve a monometallic contact system, thus, reducing process steps and avoiding intermetallic compounds. However, the native oxide of the Al seed layer needs to be removed prior deposition. As the used IL is moisture sensitive, a wet chemical treatment was not possible. Therefore, an anodic reverse pulse was applied to break the oxide and achieve well-adherent Al deposits.

The Al layers were patterned by using pattern plating with different lithography masks for different applications. Firstly, bonding frame deposition for wafer level thermocompression bonding were developed (Fig. 1) [11]. Secondly, pillars for ultrasonic flip chip bonding and thus a parallelization option for wire bonded dies were investigated (Fig. 2) [12–14]. Additionally, the bonding processes were investigated for both applications. The third dimension using vertical interconnects is still under development, but in printed circuit boards and their specific seed layer conditions a lot knowledge is gained to transfer the process to wafer level and semiconductor applications.

Currently, all depositions on wafer level are carried out without any additives resulting in rough surfaces. The future work will focus on additives for an enhanced deposition process and the development of Al alloy deposition to achieve more compatibility to sputter-deposited Al-Cu or Al-Si alloys.

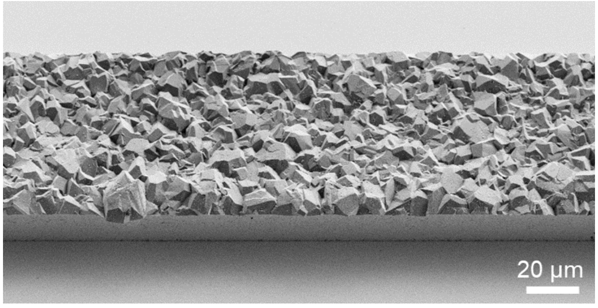

Figure 1: SEM picture of an electroplated Al bonding frame with 60 µm width

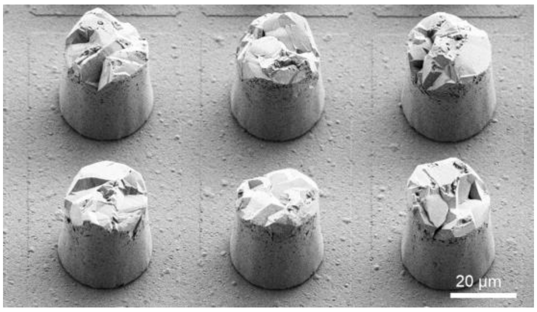

Figure 2: SEM picture of 30 µm diameter Al pillars wiith 50 µm pitch

References

[1] Y. Zhao and T. J. VanderNoot, *Review: Electrodeposition of Aluminium from Nonaqueous Organic Electrolytic Systems and Room Temperature Molten Salts*, Electrochim Acta **42**, 3 (1997).

[2] F. Endres, A. P. Abbott, and D. R. MacFarlane, *Electrodeposition from Ionic Liquids* (Wiley-YCH, 2008).

[3] J. Tang and K. Azumi, *Improvement of Al Coating Adhesive Strength on the AZ91D Magnesium Alloy Electrodeposited from Ionic Liquid*, Surf Coat Technol **208**, 1 (2012).

[4] A. Bakkar and V. Neubert, *Electrodeposition and Corrosion Characterisation of Micro- and Nano-Crystalline Aluminium from AlCl3/1-Ethyl-3-Methylimidazolium Chloride Ionic Liquid*, Electrochim Acta **103**, 211 (2013).

[5] W.-C. Sun, X. Han, and M. Tao, *Electroplating of Aluminium on Silicon in an Ionic Liquid*, ECS Electrochemistry Letters **4**, D5 (2015).

[6] M. S. Al Farisi, T. Tsukamoto, and S. Tanaka, *Electrochemically Deposited Aluminum for MEMS Thermal Actuator*, in *2021 Smart Systems Integration, SSI 2021* (Institute of Electrical and Electronics Engineers Inc., 2021).

[7] J. Li et al., *Electrodeposition of a Dendrite-Free 3D Al Anode for Improving Cycling of an Aluminum–Graphite Battery*, Carbon Energy (2021).

[8] G. Oltean, L. Nyholm, and K. Edström, *Galvanostatic Electrodeposition of Aluminium Nano-Rods for Li-Ion Three-Dimensional Micro-Battery Current Collectors*, Electrochim Acta **56**, 3203 (2011).

[9] K. V Kravchyk, Maksym, and V. Kovalenko, *Aluminum Electrolytes for Al Dual-Ion Batteries*, Communication Chemnistry **3**, (2020).

[10] M. S. Al Farisi, S. Hertel, M. Wiemer, and T. Otto, *Aluminum Patterned Electroplating from AlCl3-[EMIm]Cl Ionic Liquid towards Microsystems Application*, Micromachines (Basel) **9**, (2018).

[11] S. Hertel, M. Wiemer, and T. Otto, *Electroplating of Aluminium for Wafer Level Thermocompression Bonding*, in *Waferbond Workshop* (Halle/Saale, 2019).

[12] I. Cirulis, S. Braun, K. Vogel, F. Roscher, M. Wiemer, K. Hiller, and H. Kuhn, *Optimal Design Configuration for Aluminum Pillar Fabrication towards Fine Pitch Ultrasonic Bonding Applications*, in *2022 IEEE 9th Electronics System-Integration Technology Conference, ESTC 2022 - Proceedings* (Institute of Electrical and Electronics Engineers Inc., 2022), pp. 6–10.

[13] S. Braun, I. Cirulis, J. E. Liedtke, K. Hiller, M. Wiemer, and H. Kuhn, *Electroplated Aluminum Pillars for Ultrasonic Flip Chip Bonding*, in *55th International Symposium on Microelectronics and Packaging (IMAPS)* (Boston, 2022).

[14] I. Cirulis, U. Zschenderlein, M. Radestock, S. Braun, R. Pantou, K. Vogel, F. Selbmann, K. Steffen, B. Wunderle, and H. Kuhn, *Investigation of Gold and Aluminum Flip-Chip Bonding for Quantum Device Integration*, in *24th IEEE European Microelectronics Packaging Conference (EMPC)* (Cambridge (UK), 2023).

*corresponding author e-mail: silvia.braun@enas.fraunhofer.de