# Co metal ALD on Cu with Cyclic clean by Peroxide and Hydrazine for Inverse Hybrid Metal Bonding

**Cheng-Hsuan Kuo[1], Madison Manley[4], Jeff Spiegelman[5], Dipayan Pal[2], Rohan Sahay[4], Ravindra Kanjolia[3], Mansour Moinpour[3], Jacob Woodruff[3] Bakir Muhannad[4], and Andrew C. Kummel[2]**

[1]*Materials Science and Engineering Program, University of California, San Diego*

[2]*Department of Chemistry and Biochemistry, University of California, San Diego*

[3]*EMD Electronics* [4]*Georgia Institute of Technology* [5]*Rasirc*

Typical I/O pitches for µ-bumps range from hundreds of µm to ~50 µm for conventional flip chip stacking therefore limiting the number of I/O's. When scaling down the µ-bumps, adjacent interconnects could be shorted during the bonding process. As a result, new bonding techniques are being investigated.

Fig 1 shows the concept of inverse hybrid metal bonding by using selective Co metal ALD to bond the Cu pads followed by the dielectric in-fill by ALD. To deposit Co metal selectively, a clean Cu surface is required for uniform and conformal growth of Co metal.

In Fig 2, four types of Cu substrates fabricated by different tools were investigated. For electrochemically plated (ECP) Cu, surface oxides can be completely removed after regular UHV anneal at 415°C for 30 mins. 18% of carbon is detected by in-situ XPS indicating a monolayer of carbon is on the surface of the ECP Cu substrate after UHV anneal . Compared to ECP Cu, all other Cu substrates such as e-beam Cu(GT), sputtered Cu(GT), and sputtered Cu(UCSD) show remaining oxides and carbide contamination even after UHV anneal. This indicated that $CuO_xC_y$ is formed during the substrate fabrication process which cannot be removed by heating high temperature anneal.

Fig. 3 show the optimization of the cyclic clean by tuning the dosing ratio of HOOH to $N_2H_4$. By decreasing the dosing of HOOH, carbon content is higher but oxygen content is similar. However, in terms of surface roughness, a lower HOOH dosing ratio can improve the surface RMS roughness from 9.1nm to 2.7nm (not shown) Surface roughness is one of the key factors which directly affects the bonding temperature.

In Fig 4, Co ALD on break junction samples with different treatments was illustrated. Without any treatment, only one of the daisy chains was connected after Co ALD (Fig5(a)). UHV anneal at 415°C shows that Co only partially connected the Cu chain (Fig 5b). After 500 cyc Co ALD, the break junctions were completely connected (Fig 5d). Besides high yield, Co was selectively deposited on Cu but not on the insulating material ($SiO_2$) which is crucial for the inverse hybrid metal bonding.

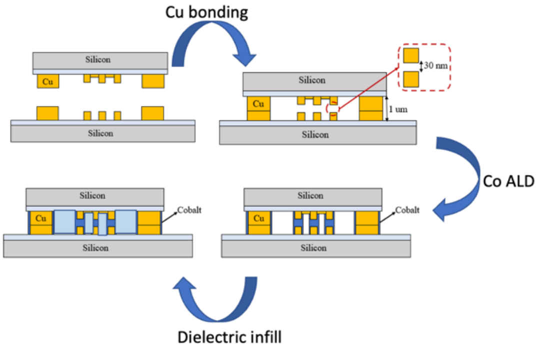

**Fig 1. Schematic of the inverse hybrid metal bonding by selective Co metal ALD**

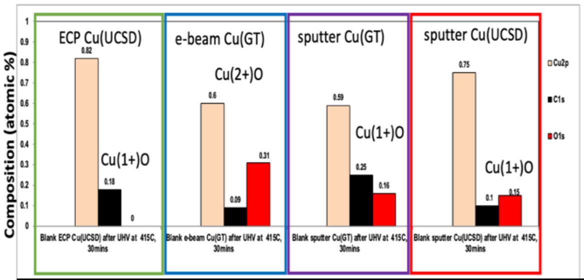

**Fig 2. Summary of XPS of UHV anneal at 415°C for 30mins on e-beam Cu (GT), sputtered Cu (UCSD), sputtered Cu (GT), and ECP Cu (UCSD).**

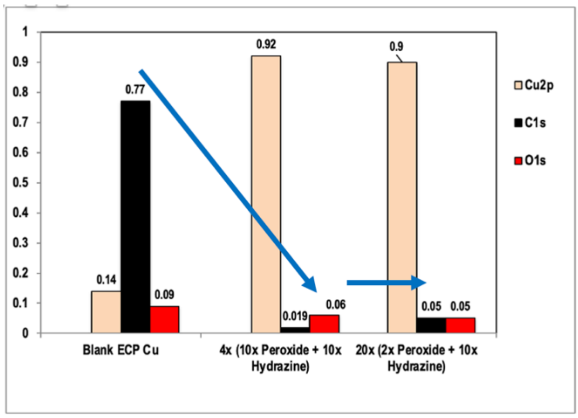

**Fig 3. Optimization of cyclic clean condition by altering the dosing ratio of HOOH to $N_2H_4$.**

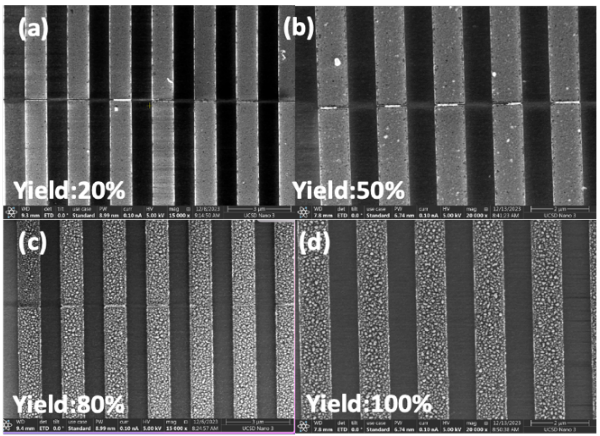

**Fig 4. SEM top-view of 300cyc Co ALD on Cu break junctions on $SiO_2$ with (a) no treatment (b) UHV anneal at 415°C (c) 300cyc Co ALD with 2 supercycle cyclic clean (d) 500cyc Co ALD with 2 supercycle cyclic clean.**