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Interrogation of Surface Roughness and Bond Force Effect

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ABSTRACT

In the macro world surface roughness is a feature undoubtedly not to be ignored. In the current trend towards the nano-scale feature in the devices related to the semiconductor and other various niche, surface roughness is being propelled as an important element. In this work the surface roughness at nano level is investigated for the adhesion interaction and influence. The samples for the roughness feature and ranges were prepared using controlled plasma etching. The wire bonding bond force parameter was chosen as the factor to be tested and shear test as the response. The shear value ranged from 13g to 22g for the low to high bond force respectively for the lower range surface roughness, for the higher surface roughness the value ranged 5g to 9g respectively. The interaction shows surface roughness has tangible effect on adhesion for a more thorough detailed investigation.

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INTRODUCTION

Every organic and inorganic entity in this realm, has one or more building block unit in them, generally more than a unit comprises a system. Surface elements play a crucial role in ensuring this harmonies bonding. This system can range from a biological cell to a towering sky scrapper [1,2,3,4 & 5] the cohesive and adhesive forces determine the structural integrity along with surface features. The entry of micro and nano technology has reinvented this niche on surface metrology into a new cornucopia in this paradigm shift of research. The electronic industry has gone through multiple phases of evolution and is still developing dynamically. Individualistic application electronic devices were in the past era, now devices have multiple built-in applications. The component count in each device has also increased as the evolved device functionality. The integrity of this functionality is solely dependent on its interconnection quality. As the devices become smaller with more application, this requires intricate design which is in line with the interconnection moving towards micro and nano joints. There were work done [6 & 7] on gold ball bonding adhesion is influenced by both ultrasonic force and time of the process, the studies were done on aluminium bond pad, surface roughness effect were not discussed except on the native oxide formation on the bonding surface. There were also similar investigation on the oxide layer influence of bondability and using ultrasonic force to overcome this layer [8].

Krzanowski, Razon and Hmiel [9] work have implored into surface roughness of thin film and its effect on bonding quality. Investigations show for both 0.5 µm and 1 µm films with high hardness levels and low roughness were not bondable. The ball shear tests results also showed that 0.5 µm thin film gave low shear strength. Thin film, high hardness and smooth surface will generate poor bondability. According to the study done by Greenwood & Williamson [10], the effects of bonding pressure become more significant when the morphology of the bonding materials becomes more important. When the dimension of roughness is higher, the actual contact area may be reduced significantly. By applying of bonding pressure will helps to flatten the surface of bonding materials, and thus increase the actual contact area, but this roughness has its limits of positive influence over bonding. Adhesion and bond pad surface investigations [11, 12, 13 & 14] have shown elemental composition, thickness, hardness, roughness, and surface contamination, affect the success of the solid state joining process. The above investigation have superficially discussed on the surface roughness influence of the bonding yield, a conclusive quantifying summary were not provided and discussed.

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Theoretical:

Adhesion science has been an important part of mankind since the dawn of weapon making, with technological advancement towards nano niche, this is leading to a cornucopia of research investigations in understanding at this level. The role of both interfacial and adhesion has significant role where friction, wear, triboelectrification, surface contamination control in microelectronics and particle adhesion. The mentioned roles have embedded roles in the field of both electronic packaging and semiconductor fabrication [15].

The adhesion and contact mechanism revolves around Hertzian theory. JKR (Johnson, Kendall and Roberts) theory is an improvement over the Hertzain theory, so the theory is related to the elastic material properties and the interfacial interaction strength of a contact area. Similar to the Hertzian theory, this JKR theory is also limited to elastic deformation of sphere-sphere contacts [16]. The other theory that also considers the Van der Waals interaction for the elastic deformation was the theory proposed by Derjaguin, Muller, and Toporov [17], which is also known as the DMT theory. This theory considers Van der Waals interactions outside the elastic contact regime. This theorem was simplified to Bradley's Van der Waals model when the two materials were separated to infinity length [17].

Silicon direct bonding work has been done by Liao [18], two surfaces of one as a rigid flat surface and the other having a combined Gaussian-distributed roughness. The work states that the mainstream research focuses on:

i. The mechanism of elastic contact, transition from elastic to plastic contact and full plastic contact.
ii. The contact of rough surfaces in the presence of cohesive force.
iii. The impact of asperity interactions on contact.

The work here deals two kinds of micro-roughness surface which are nano roughness and waviness, termed as asperities here. The work analyzed the relations among the elastic stress due to surface deformation, the adhesive force due to surface activation and the distance due to surface separation, and this was discussed in detail the impact of separation distance on the bonding forces.

The relationship provided by Greenwood and Williamson [10] was for the relationship of contact load and the real area of contact of a flat rough and ideally smooth flat surface. Beheshti and Khonsari [19] work also stresses on scarce experimental determination of contact parameters, very minimal data is available to the best of the author’s knowledge here.

The models reviewed here have been employed using elastic bulk formula in the line contact to identify the pressure profile, width and real area of contact in the measure of surface roughness impact on the contact characteristics. In this work, most models are based on Greenwood and Williamson [10], the Equations: 1.1, 1.2, 1.3, 1.4, 1.5, and 1.6 is shown,

$$P(h) = n\beta\sigma E' A_n \frac{4}{3}\sqrt{\frac{\sigma}{\beta}} \int_{(h-y_s)/\sigma}^{\infty} (\overline{\omega})^{3/2}\ \phi^*(z^*)dz^* = n\beta\sigma E' A_n \times \{\Phi_{\mathrm{GW}}\ (h)\} \tag{1.1}$$

$$A(h) = \pi n\beta\sigma A_n \int_{\frac{h-y_s}{\sigma}}^{\infty} (\overline{\omega})\, \phi^*(z^*)dz^* \tag{1.2}$$

Where

$$\phi^*(z^*) = \frac{1}{\sqrt{2\pi}}\left(\frac{\sigma}{\sigma_s}\right) e^{-(\sigma/\sigma_s)^2\ (z^{*2}/2)}\ z^* \tag{1.3}$$

$$z^* = \frac{z}{\sigma} z^* \tag{1.4}$$

$$\overline{\omega} = z^* - \frac{h-y_s}{\sigma} z^* \tag{1.5}$$

$$\frac{1}{E'} = \frac{1-v_1^2}{E_1} + \frac{1-v_2^2}{E_2}\ z^* \tag{1.6}$$

Methodology:

The next phase investigation here would be to investigate surface roughness interaction with bonding force using ball shear as the response. As stated earlier, the surface roughness for each aluminium pad was produced by using controlled plasma parameters as shown in Appendix A. The applicable surface roughness range derived from the experiment is from 0.1nm till 15nm. The experiments conducted here were done in three sets, each set has an aluminium roughness of maximum, median and minimum from the stated range earlier. In each set 16 runs were executed, each run constitutes of five pieces of wafer with aluminium coated layer acting as bond pad.

In the each pieces of wafer five times of bonding was tested. This calculates, for each run a total of 25 wire bond was done and an equal number of ball shear was implemented, this number if extended to the total set would sum up to 400 each for wire bonds and ball shears in each set of maximum, median and minimum surface roughness division.

The continuation from this phase of work would be in determining the relevancy of the roughness range. In this extended experiment run, all the bonding parameter were set to constant, the ball shear was measured against the roughness range. In this section the main factor values used in wire bonding would be, 2.5W (ultrasonic force), 3.0g (bonding force), 2.9s (bonding time) and 110°C (bonding temperature). The range of surface roughness investigated here would be from 0.0nm to 15.0µm, whereby 1.0nm would be the division with a total 15 trials. In each trial eight wire bonds were performed on each piece of wafer. Figure 1, illustrates the experimental runs executed in the trial runs.

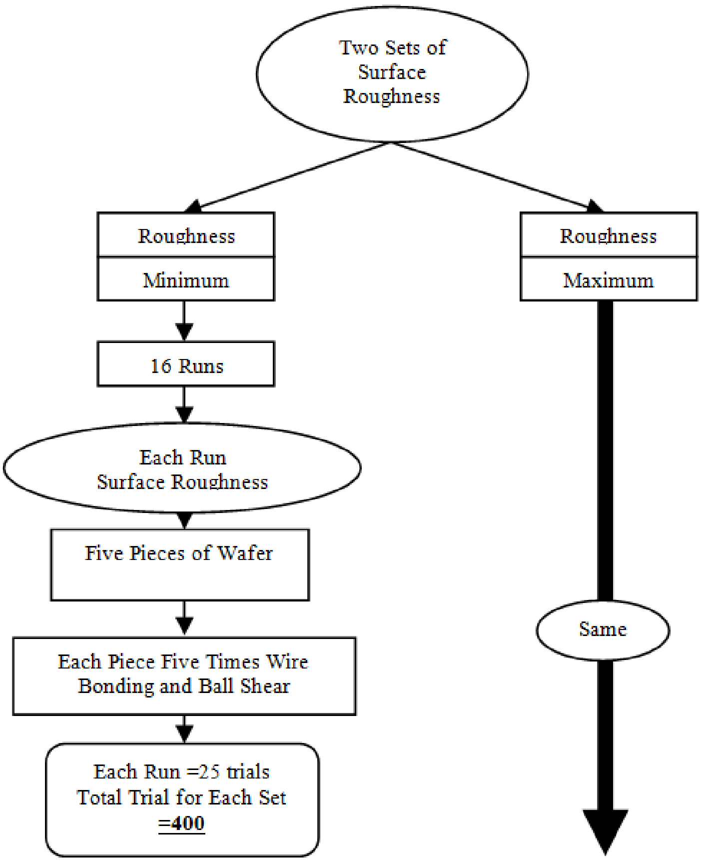
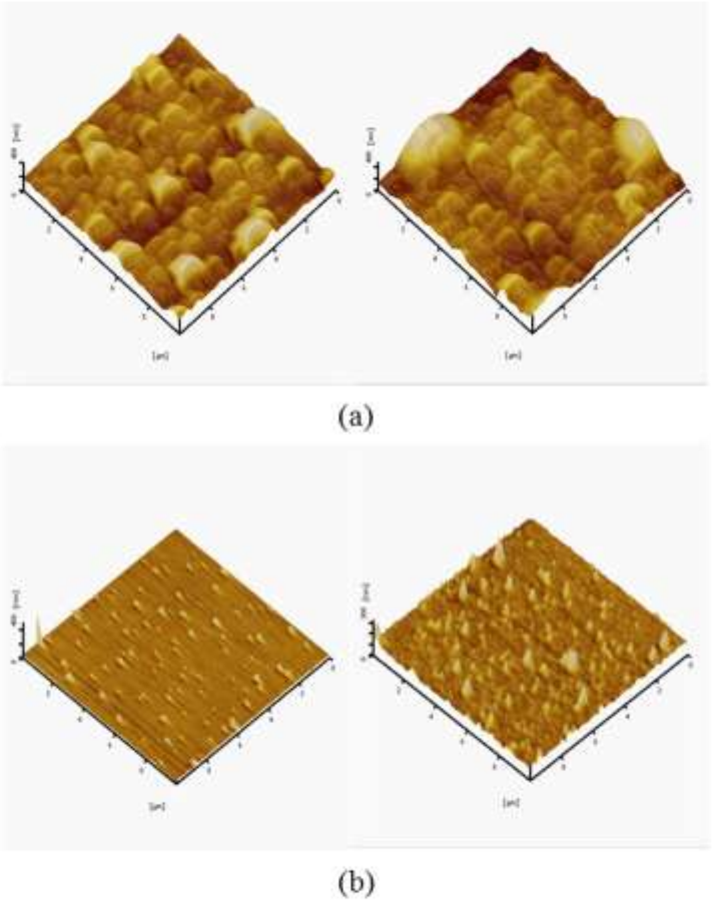


Fig. 1: Process flow of the experimental runs designated in this investigation.

RESULT AND DISCUSSION

In this section, the initial analysis were on segregating the surface roughness into high and low categories. This is to ensure there are two levels of surface roughness to see the response to the two level of bond force. Figure 2 depicts, two categories of surface roughness, high and low respectively, these images were obtained using atomic force microscope (AFM) model SPA400, SII Nanotechnology.


(a)

(b)

Fig. 2: (a) Maximum surface roughness AFM image and, (b) Minimum surface roughness AFM image.

Figure 2 shows the asperities of the surface captured in AFM has different feature distinctly for this two surface categories. Surface asperity for low roughness category is minimal and has more defined flatness compared to that of the higher roughness.

Table 1 and 2 shows the tabulated results for the ball shearing response on both the designated surfaces. The standard deviation calculated for both the low and high surface roughness experiment are, 0.10 and 0. respectively, which translates to 8% and 9% deviation respectively from the average value of surface roughness. In this experiment all the other main factors have been made constant. The tabulated results approximately shows the lower surface roughness has higher average ball shearing values, Figure 3 depicts the plot and effect better.

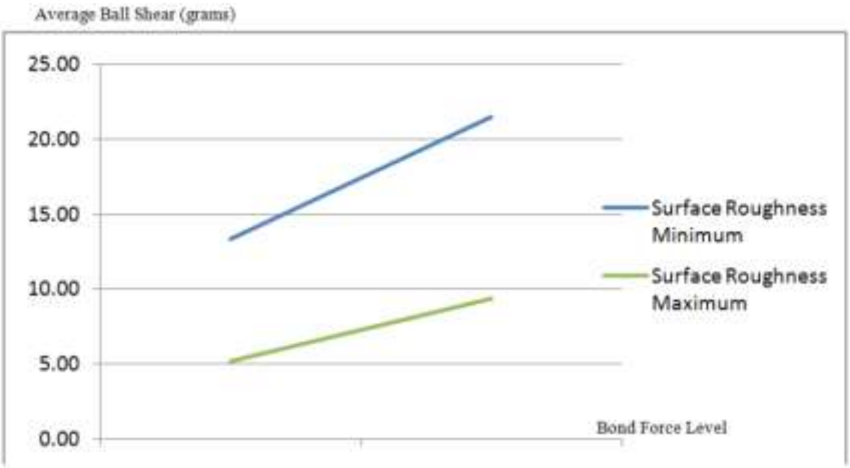


Fig. 3: Two level bond force using two sets of surface roughness data.

Table 1: Results for low surface roughness with ball shear as the response.

Low Level Surface Roughness							
Parameter	Ultrasonic Force (W)	Bonding Force (g)	Bonding Time (s)	Bonding Temperature (°C)	Average Ball Shear (g)	Average R_a (nm)	Standard Deviation Average R_a
1	2.50	3.0	2.90	110.00	21.40	0.90	0.10
2		3.0			21.80	0.81	
3		3.0			23.20	1.05	
4		3.0			22.80	0.98	
5		2.0			15.40	1.07	
6		2.0			14.20	0.88	
7		2.0			14.80	0.92	
8		2.0			14.60	0.98	
9		3.0			21.80	1.04	
10		3.0			20.60	0.80	
11		3.0			20.60	0.73	
12		3.0			20.00	0.86	
13		2.0			13.20	0.82	
14		2.0			12.00	0.94	
15		2.0			11.20	1.02	
16		2.0			11.00	0.89	

Table 2: Results for high surface roughness with ball shear as the response.

Low Level Surface Roughness							
Parameter	Ultrasonic Force (W)	Bonding Force (g)	Bonding Time (s)	Bonding Temperature (°C)	Average Ball Shear (g)	Average R_a (nm)	Standard Deviation Average R_a
1	2.50	3.0	2.90	110.00	9.80	10.20	0.83
2		3.0			9.20	11.20	
3		3.0			8.00	11.20	
4		3.0			8.80	11.35	
5		2.0			6.40	12.50	
6		2.0			5.60	13.20	
7		2.0			5.00	13.10	
8		2.0			4.80	12.50	
9		3.0			7.00	11.50	
10		3.0			5.40	12.20	
11		3.0			7.20	11.40	
12		3.0			5.60	13.20	
13		2.0			5.20	11.80	
14		2.0			4.20	12.20	
15		2.0			4.00	12.10	
16		2.0			3.00	11.80	

Figure 3 combines two plot to paint a better overall picture for comparison between the roughness divisions. The lower level of the bond force has the highest ball shear value compared to that of with the higher surface roughness. This has been outlined in Packham's [20] work where higher roughness scale has high probability of less contact between surfaces. The results in the experimental concur with the previous work done in ANSYS simulation study of different surface morphology [21, 22 & 23].

Conclusion:

The results here distinctly show surface roughness has a prominent role on gold ball adhesion. Surface roughness has proven its criticality on the adhesion investigated at nano-scale level. This crucial information is important for development work with devices and interconnections at micro and nano level. A method to visualize the adhesion need to be devised as the ball shear gives the value in numerical term whereby the actual adhesion is clouded.

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