SURFACE ROUGHNESS AND ADHESION ANALYSIS STUDY ON ULTRASONIC GOLD BALL ONTO ALUMINIUM BOND PAD

by

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LIST OF ABBREVIATION

MEMS	Micro-mechanical Systems
LED	Light Emitting Diode
FEM	Finite Element Modelling
FEA	Finite Element Analysis
FE	Finite Element
IC	Integrated Circuit
C4	Controlled Collapsed Chip Connection
TAB	Tape Automated Bonding
EFO	Electronic Flame Off
FAB	Free Air Ball
IMC	Intermetallic Compound
BBOS	Bond Ball on Stitch
BSOB	Bond Stitch on Ball
AFM	Atomic Force Microscope
ENIG	Electroless Ni Immersion Gold
SEM	Surface Electron Microscope
CTF	Critical to Function
OM	Optical Microscope
EDX	Energy Dispersive X-Ray
HTS	High Temperature Storage
JKR-Theory	Johnson, Kendall and Roberts Theory
DMT	Derjaguin, Muller, and Toporov
GW	Greenwood and Williamson
CEB	Chang, Etison and Bogy
ZMC	Zhao, Maietta and Chang

KE	Kogut and Etison
JG	Jackson and Green
CTE	Coefficient of Thermal Expansion
HAZ	Heat Affected Zone
DOE	Design of Experiment
SUPS	Structures Under Pads
COUB	Chip Out Under Bump
DCB	Direct Copper Bonding
COB	Chip on Board
MCM	Multi Chip Module
BPSG	Borophosphorosilicate Glass
IMD	Intermetallization Dielectric
IGBT	Insulated Gate Bipolar Transistor
JEDEC	Joint Electron Devices Engineering Council
NCP	Non Conductive Paste

LIST OF SYMBOLS

E	elastic modulus
v	Poisson’s ratio
D	sphere diameter
d	spot diameter
F	load
W	short-range work of adhesion
σ	applied stress
ε	resulting strain
U	energy of interaction
α	respective polarizabilities
I	respective ionization energies
r	distance between the two molecules
ε_0	permittivity of a vacuum
k	Boltzmann’s constant
T	absolute temperature
R	radius of curvature
ω	deformation
P_L	contact force
F_c	cohesive force
F_e	external force
P	contact load for the contact of two flat surfaces with constant mean separation
h	separation based on surface heights
n	asperity density
β	asperity radius

σ	standard deviation of surface heights
$E^{'}$	effective modulus of elasticity
A_n	nominal contact area between two rough flat surfaces
y_s	distance between the mean of summit heights and that of the surface heights
$\bar{\omega}$	dimensionless interface
$\phi^*(z^*)$	dimensionless standard normal distribution function
$\Phi_{\mathrm{GW}}\ (h)$	function representing different micro asperity contact models for the contact load
A	real contact area between two rough flat surfaces
z	asperity height measured from the mean line of summit heights
z^*	dimensionless asperity height
E_1	moduli of elasticity of first surface
E_2	moduli of elasticity of second surface
v_1	poisson ratio of the first surface
v_2	poisson ratio of the second surface

Kajian Analisis Kekasaran Permukaan Dan Daya Lekatan Untuk Bebola Emas Ultrasonik Ke Atas Pelogaman Pad Ikatan Aluminium

ABSTRAK

Kemajuan teknologi dalam bidang elektronik mikro dan nano telah mengubah aspek penyambungan dalaman dalam sambungan elektrik. Kelekatan permukaan fabrikasi peranti elektronik telah melonjakkan elemen tribologi pada lapisan dan ikatan peranti sebagai satu elemen penting. Kekasaran permukaan telah menjadi bahagian penting dalam sistem makro elektro-mekanikal ,dalam kemunculan mikroelektronik kekasaran permukaan telah sekali lagi menjadi tumpuan bidang penyelidikan. Dalam karya ini, kajian yang disiasat adalah mengenai sifat kekasaran permukaan terhadap bola emas pada pad ikatan aluminium. Dengan menggunakan pendekatan rekabentuk eksperimen (DOE), tenaga ikatan sebagai parameter fungsi telah dipilih dalam kajian ini untuk mengkaji pengaruh kekasaran permukaan. Julat kekasaran permukaan pad ikatan aluminium yang berbeza pada kepingan wafer telah dihasilkan dengan menggunakan tetapan plasma yang berbeza. Dengan menggunakan tiga nilai daya ikatan yang berbeza, pelbagai ikatan bola emas telah dilakukan ke atas beberapa siri kekasaran permukaan yang berbeza pada pad ikatan aluminium untuk tiga ujian. Nilai purata kericihan bebola terhadap kekasaran permukaan telah diplot pada box-plot yang telah diubahsuai. Ketiga-tiga ujian menggambarkan bentuk polinomial yang sama dengan pekali negatif yang mendahului. Dengan kaedah pembezaan yang mudah ditambah pula dengan nilai sisihan piawai dari ketiga-tiga ujian tersebut, kekasaran permukaan yang dioptimumkan telah diperolehi daripada persamaan-persamaan yang telah dihasilkan. Nilai kekasaran permukaan yang optimum dalam julat 2.10 nm hingga 6.38 nm. Eksperimen bekas-tapak telah dilakukan untuk memahami dan mengaitkan dengan eksperimen ricihan bola. Eksperimen bekas tapak tersebut menunjukkan pemahaman yang lebih baik terhadap kelekatan tanpa nilai ricihan. Kelekatan bekas tapak telah dijadualkan dan disusun, dengan menggunakan plot peratusan bekas tapak terhadap kekasaran permukaan telah diplot. Plot tersebut menggambarkan bentuk polinomial yang sama seperti eksperimen-eksperimen sebelumnya. Kelekatan peratusan bekas tapak yang tertinggi juga dalam julat yang diperolehi sebelumnya. Peratusan kelekatan sisa bekas tapak melebihi 80% pada ikatan tapak Aluminium berada di dalam julat kekasaran optimum iaitu 2.10 nm hingga 6.38 nm. Kesimpulannya, kekasaran permukaan pada peringkat mikro menjadi sifat kritikal yang penting untuk memastikan kualiti ikatan wayar. Pendekatan eksperimen juga telah memberikan kaedah baru mendapatkan julat kekasaran permukaan optimum yang sesuai untuk kualiti and keteguhan kelekatan ikatan wayar pada pad ikatan. Kajian ini telah berjaya menunjukkan kepentingan permukaan kekasaran terhadap proses ikatan wayar.

Surface Roughness and Adhesion Analysis Study on Ultrasonic Gold Ball onto Aluminium Bond Pad Metallization

ABSTRACT

The advancement of technology in the micro and nano electronic niche has changed the aspects of interconnection of electrical connectivity. Surface adhesion of electronic device fabrication has propelled tribology element on layers and bonding of this devices as an important element. Surface roughness has been an integral part of macro electro-mechanical systems, in the advent of microelectronics surface roughness has been again a focus research area. In this work, a study on surface roughness attribute in gold ball adhesion on aluminium bond pad was investigated. Using design of experiment approach (DOE), bond force as a critical to function parameter was chosen in this work to study surface roughness influence. A range of different surface roughness of aluminium bond pad on pieces of wafer was created using different plasma settings. Using three different values of bond force, multiple gold ball bonding were performed on the series of different surface roughness on aluminium bond pad for three trials. A modified box-plot was plotted for average ball shear value against surface roughness range. All three trials depicted similar polynomial plot trend with a leading negative coefficient. Using simple differentiation coupled with the standard deviation value from the trials, an optimized range for surface roughness was obtained from the equations created. The optimized ranges of surface roughness deduced from this experiment were from 2.10 nm till 6.38 nm. A final footprint experiment was done to understand and correlate to the ball shear experiments. The footprint experiment shows a better understanding of adhesion without shear value. Footprint adhesion scales were tabled and ranked, using this footprint adhesion plot against surface roughness was plotted. The plot depicted similar polynomial trend as the previous experiments. The highest footprint adhesion was also within the range obtained previously. The adhesion of footprint more than 80% gold ball remnant on the aluminium bond pad were within the optimized surface roughness range of 2.10 nm till 6.38 nm. It can be finally concluded that surface roughness at micro level becomes an important critical attribute to ensure the wire bond quality. The experimental approach has also given new means of obtaining the suitable optimized surface roughness range for a quality and robust wire bond adhesion onto bond pads. The work has successfully established surface roughness importance in the wire bonding process.

CHAPTER 1

INTRODUCTION

1.0 Overview

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 (Schmalz, 1929; Schmalz, 1936; Williamson, 1967/1968; Abbott & Firestone, 1933; Whitehouse, 1978) 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. All interacting surface have residual stress which correlates into dynamics of this, which then brings about another niche into surface metrology known as tribology. The micro-tribology challenges will be to study the rules of macro being relevant here. Using Figure 1.1 (Whitehouse, 2009) which uses the surface between gaps and their transverse velocity as ordinate and abscissa axis respectively to enable tribological function comparison. In this Figure 1.1, (a) is the co-ordinate system, (b) depicts different tribological regimes and (c) relates and shows different tribological assimilation into the scheme.

Miniaturization factor and the appetite for high technology gadget has been an integral catalyst in the recent decades, which can be visualized in Figure 1.2, where the advancement importance of surface metrology is inevitable.

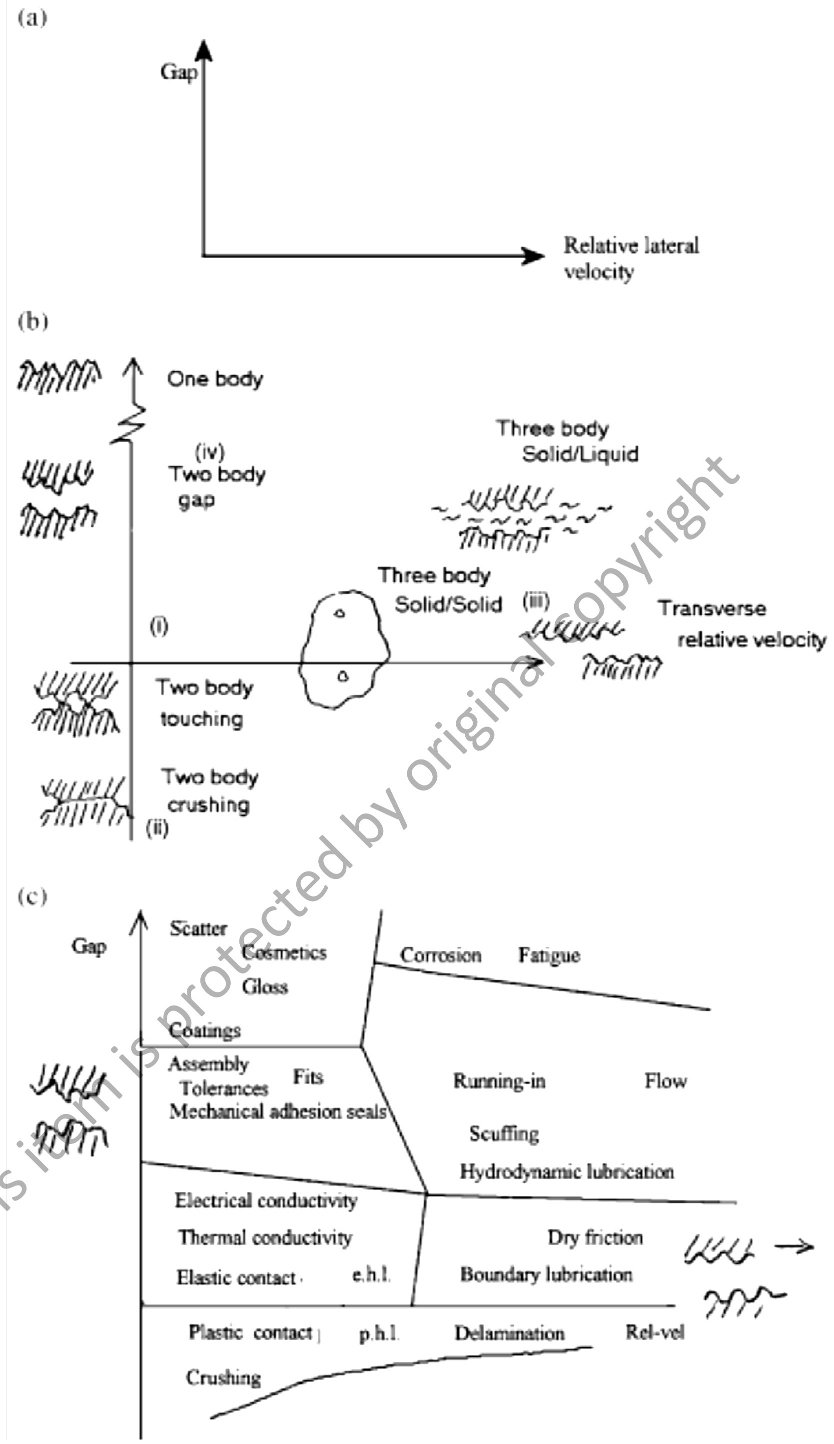

Figure 1.1: Tribological Function Comparison (Whitehouse, 2009)

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. Figure 1.3 outlines the surface features in relation measurement scale to application niche. It is clearly shown that niche areas such as micro-electro-mechanical systems (MEMS) palced needs surface roughness as an importance feature. Roughness contributes immensely as the scale goes down to micro and nano. It also shows as the scale reduces the geometrical features have less significant influences, even roughness beyond the scale of nano at molecular level has minimal effect.

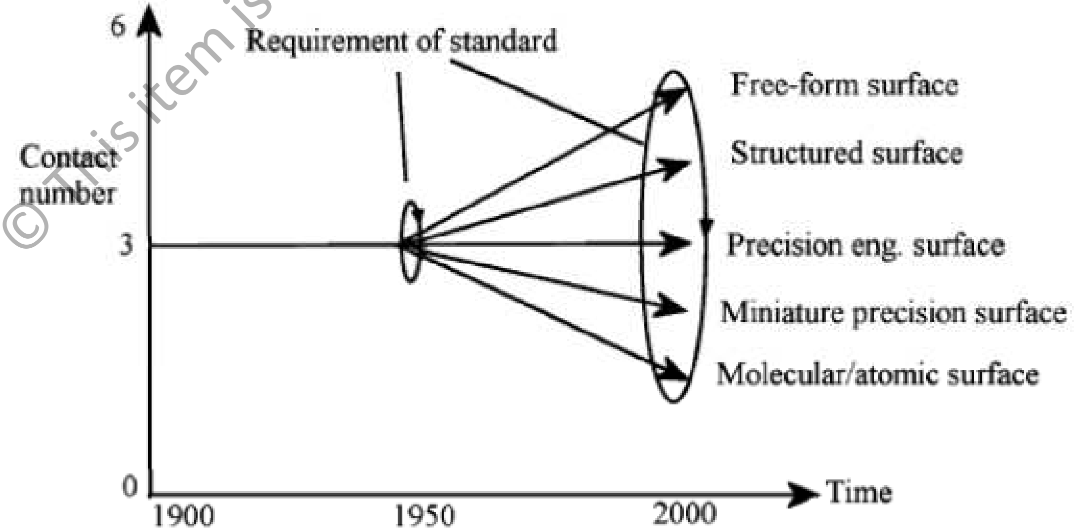

Figure 1.2: Timeline and expansion of surface metrology development (Whitehouse, 2009)

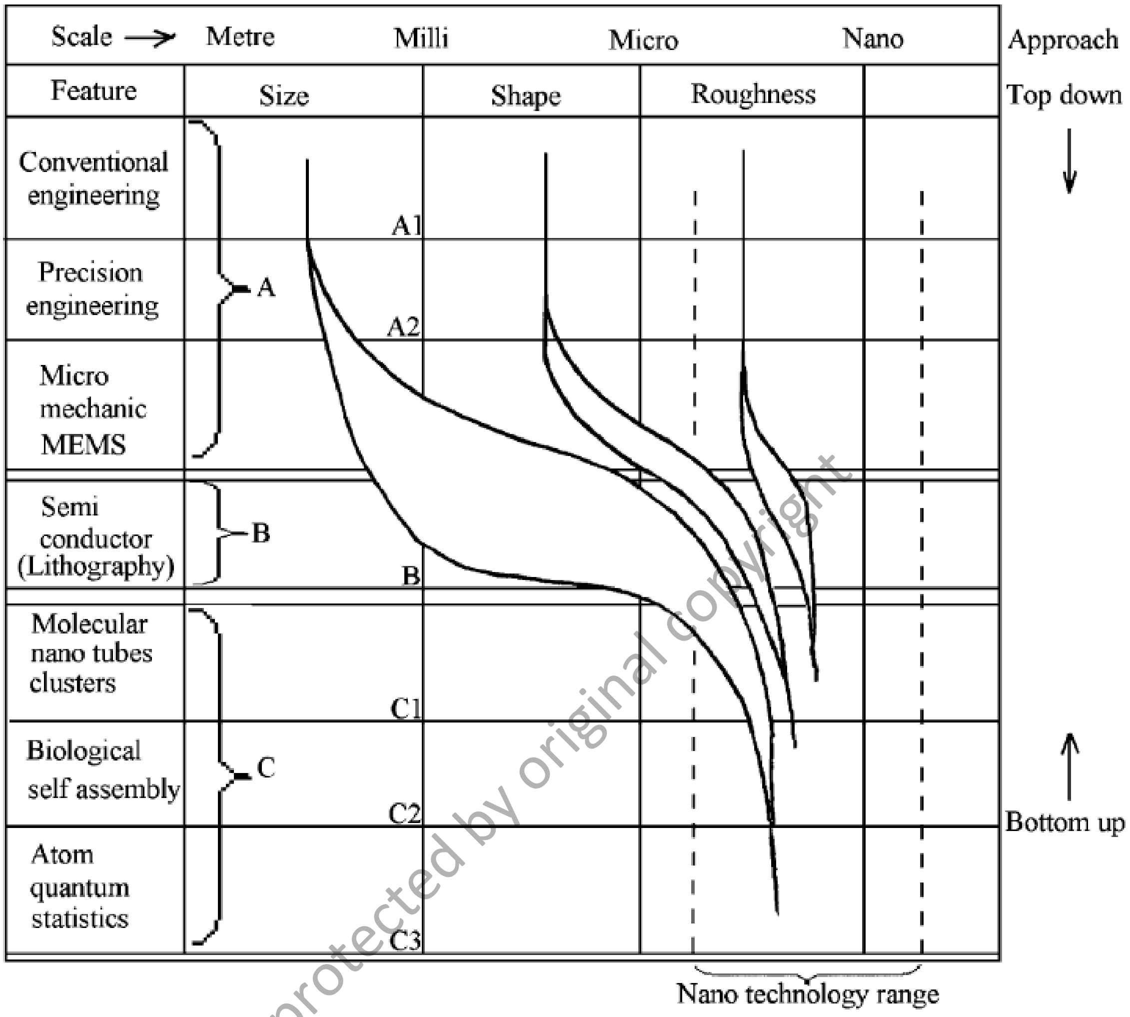

Figure 1.3: Surface feature and scale measurement towards application relations (Whitehouse, 2009)

1.1 Problem Statement

Surface science is being propelled to the forefront as the advancement of technology evolves from micro towards nano. MEMs, microfluidic or other miniature packages have surface metrology characterization study. Surface to surface adhesion strength has surface energy, bonding material and the method applied as the major influences. Having viewed the prior statements, it can be also stated roughness has an important role to play here.

As of year 2008 according to Harman (2010), there are approximately 9 billion wire bonded per year on the planet. This rate is still in the acceleration mode, even with the emergence of variant flip chip technologies, the replacement is not seen in near foreseeable future. The other fact about this particular interconnection is its infrastructure availability in the industry is so massive, it's an integral joint for ICs, transistors, LEDs and etc. In this aspect the wire bond failure contributes 25% of the total reliability problems of electronic packages (Charles Jr, 2003; Kelly, 2000; Zhang, Van Driel, & Fan, 2006; Driel, Silfhout, & Zhang, 2009). These causes of failure and reliability issues are still unknown mainly in the thermo-mechanical related issues (Abbott & Firestone, 1933). There suggestion using a nonlinear and parametric finite element model, where occurrence of wire failure can be due to:

i. The interaction between the wire and molding compound

ii. The influence of manufacturing and reliability testing

iii. The influence of interfacial delamination

Plasma treatment on wire bonding surface improves the bonding adhesion onto the bond pad, research on this effect and reliability has been done by many (Driel, Silfhout, & Zhang , 2009; von Arnim, Fessmann, & Psotta, 1999; Lin, 2003; Lee, Mayer, Zhou, & Hong, 2007 ; Ding, Kim, & Tong, 2006b ; Knotter, Rink, Claassen, & Philipsen, 2011; Chong et al.,2000; Maruo, et al., 2004) . Wire bonding process has been investigated and optimized since the advent of it (Lo & Tsao, 2002; Guzman, Mahaney, & Strode, 1993; Tay, Yeo, & Wu, 1995; Jr, 2001; Wang, 1993; Nan, Mayer,Zhou, & Persic, 2011; Charles Jr, 2003; Ebel, Jeffery, & Farrell, 1982; Tong, 1995; Chen, Lin,& Yang, 2012; Sauli et al., 2012a; Sauli et al., 2012b ; Sauli et al., 2012c, Sauli et al., 2012d; Sauli, Retnasamy, Shapri, Taniselass, & Ong, 2013). The surface of bond pad and its roughness feature has been investigated at a minimal degree to the best of the author's knowledge. Beheshti and Khonsari (2012) has stated about the difficulty in obtaining surface contact parameters whereby published work is scarce in this niche. The work mentioned here is about the total investigation of surface roughness and adhesion study. Understanding the surface roughness on adhesion has a great importance in the field of electrical interconnection. This industry has a roadmap towards smaller devices, where the fabrication and interconnection levels are migrating towards micro and nano scales. Figure 1.3, has clearly depicted this, with wire bond still dominating and evolving together with this trend, thus the importance of the surface feature is inevitable. The wire bond industry has been shifting towards smaller wires and finer capillaries in parallel. The surface treatment on bond pads using plasma removes contamination and also affects the surface morphology. Skirting around the macro world the roughness feature will have intermittent effect, but smaller wires and smaller bond pad areas will have distinct difference as Figure 1.3 states.

Bond pads in the wire bond process is normally cleaned prior to bonding, whereby the plasma process is used here. Plasma also has an effect on surface roughness and the work of its influence on various aluminium surface roughness and there are many work in this area(Pan, Chi, Wei, & Di , 2009; Pal, Ghatak, De, & DasGupta, 2008; Zou et al., 2011; Gogolides et al., 2004; Mellali, Fauchais, & Grimaud, 1996 ; Pigeat, Miska, Bougdira, & Easwarakhanthan, 2009; Prysiazhnyi, Zaporojchenko, Kersten & Černák, 2012; Chung, Rhee,Han, & Ryu, 2008; Prysiazhnyi, Svoboda, Dvořák, & Klíma, 2012 ; Martin, 2013). Understanding the adhesion of ball wire bonding to a bond pad using surface roughness feature has minimal work done to the best of the author’s knowledge. In this angle, there mainly three type of wire bonding wires and many type of bond pad metallization. The process parameter and the bonding reliability is not the focus here, hence a well-established platform with optimized parameters and process is needed which in line has minimal noise factors. Extensive study have been done using Al film and Au wire whereby bonding features,