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The Wetting Properties of UBM-coated Si-wafer to the Lead-free Solders in Si-wafer/Bumps/Glass Flip-Chip Bonding System

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Abstract

In an attempt to estimate the wetting properties of wettable metal layers by wetting balance method, an analysis of wetting curves of the coating layer was performed. Based on the analysis, wetting properties of UBM-coated Si-plate were estimated by the new wettability indices. The wetting curves of the one and both sides-coated UBM layers have the similar shape and show the similar tendency to the temperature. So the wetting property estimation of one side coating is possible with wetting balance method. For UBM of Si-chip, Cr/Cu/Au UBM is better than Ti/Ni/Au in the point of wetting time. At general reflow temperature, the wettability of high melting point solders(Sn-Sb, Sn-Ag) is better than that of low melting point ones(Sn-Bi, Sn-In).The contact angle of the one side coated plate to the solder can be calculated from the force balance equation by measuring the static state force and the tilt angle.

1. Introduction

The flip-chip technology has the largest packaging density and excellent electrical signal transmission property. So it is regarded as the next generation technology after CSP and μ-BGA.[1] The Si-chip on glass flip-chip bonding system in Fig. 1 is applied to optoelectronics and MEMS(Micro Electronic Mechanical System). The bare glass, Si-wafer and Al interconnection layers do not wet at all to the solder. So, to guarantee the wettability, wettable metal layers are deposited on the Si-chip and Glass substrate: UBM(Under Bump Metallurgy) for Si-chip and TSM(Top Surface Metallurgy) for Glass. The purpose of this work is to develop a way to estimate the wetting properties of one side-coated UBM layer to the molten solder with the wetting balance method. Wetting balance method has the merits of test-simplicity and good reproducibility.[2] One side coating is, naturally, more economical than both sides coating in the wetting test. And virtually, it is not so easy to get the same film quality on both sides of Si-plate. The main reason is that for both sides coating, we should coat the plate twice. But the film coated in the previous process is affected by the next coating process. The meniscus of one side coating is different from that of both sides coating because when the wetting properties of the both surfaces are different, the specimen tilts to more wettable side. The wetting curves of one side coating also have the different characteristics from those of both side-coated ones. So, new analysis and new wetting indices for one side coated UBM are required. In this work, we intended to analyze the wetting curves of one side-coated layer, and on the basis of the analysis, we estimated the wetting properties of the UBM coated Si-wafers.

2. Experimental

<Specimen Preparation>

For substrate, both side-polished (100) p-type Si-wafer was used. The specimen dimension of 1cmx2cm was adopted. Two kinds of UBM, Cr/Cu/Au(C1, C2, C3) and Ti/Ni/Au(N1), were deposited sequentially by E-gun evaporation with the thickness of Table 1. C1 and C3 have different Cu layer thickness so we intended to investigate the effect of Cu layer thickness on the wetting properties. We did not deposit the Au layer on C2 to examine the role of Au protection layer. UBM C2 was deposited not only on one side but also on both sides of

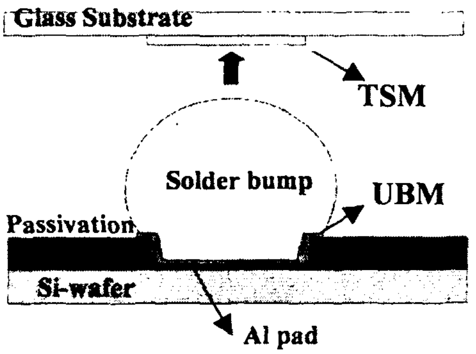

Fig.1. Si-chip on glass flip-chip bonding

the Si-plate to investigate the difference in their wetting curves. The wetting test results showed that the solders are non-wettable to the UBM C2 without flux due to the natural oxide on Cu layer. So, in testing UBM C2, R-type flux was used. The other UBMs were tested without flux to examine the fluxless wetting properties to the solders.

Table 1. Thickness of Metal layers in UBM of Si-wafer

	Wafer1(C1)	Wafer2(C2)	Wafer3(C3)		Wafer4(N1)
Au	500Å	0	500	Au	500
Cu	1000	5000	5000	Ni	1000
Cr	700	700	700	Ti	700

<Wetting Test>

The wetting balance tester, RHESCA SAT-5000 was used. The immersion speed was 5mm/s; immersion depth, 3mm; the immersion time, 10 or 20sec. For solders, Sn-37Pb, Sn-3.5Ag, Sn-5Sb, Sn-57Bi, and Sn-51In alloys were used. The test temperature was set in accordance with the melting points of each solder. For Sn-Pb, the test temperatures were 210, 230 and 250℃; for Sn-Ag, 250, 270 and 290℃; for Sn-Sb, 270, 290 and 310℃; for Sn-Bi, 170, 190, 210℃; for Sn-In, 150, 180, 210℃, respectively.

3. Results and Discussion

<Comparison of Wetting Curves of One & Both sides UBM C2-coated Si plate>

Fig. 2 shows the wetting curves of one and both sides UBM C2-coated Si-plates for Sn-Pb and Sn-Ag, respectively. In case of both side-coated specimens, the curves are not different from the conventional wetting curves of Cu plates. So the wetting indices like, wetting time and equilibrium force can be used to estimate the wetting properties. On the other hand, in case of one side-coated specimens, a great part of their wetting curves form in the negative region of the force, due to the non-wettable side. So new analysis and new wetting indices are required. There is, however, similarity in the curve shape between one and both sides-coated specimen. And they also show the similar transition tendency to the temperature. For example, the maximum wetting forces of one and both sides-coated specimens for Sn-Pb and Sn-Ag are displayed in Fig. 3. In both cases, the maximum wetting force increases with an increase in temperature for Sn-Pb and Sn-Ag solder. And this tendency is more conspicuous in the one side-coated specimen. Fig. 4 demonstrates the characteristic wetting time of one and both sides coated specimen. The characteristic wetting time is defined as the time when the wetting force reaches the two-thirds of the maximum wetting force. In both cases, the characteristic wetting time, reasonably, decreases with increasing temperature. To sum up, the wetting curves of the one and both sides coated layers have the similar shape and the indices which characterize the curve shape show the same tendency to the temperature. So, we can say with fair certainty that the wetting property estimation of one side coating is possible with wetting balance method.

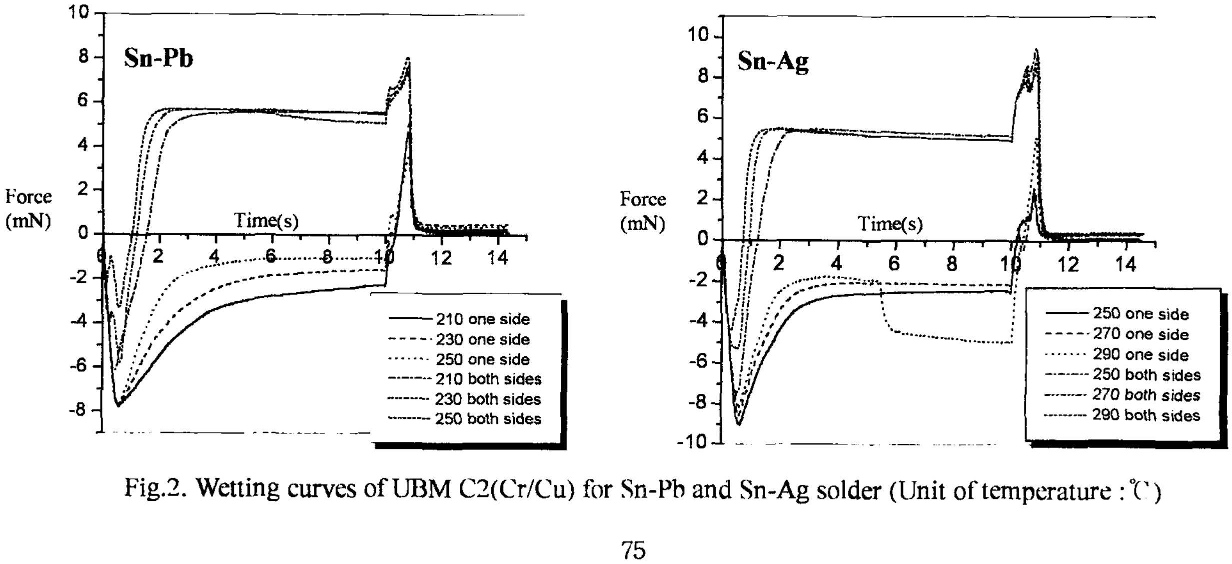

Fig.2. Wetting curves of UBM C2(Cr/Cu) for Sn-Pb and Sn-Ag solder (Unit of temperature : ℃)

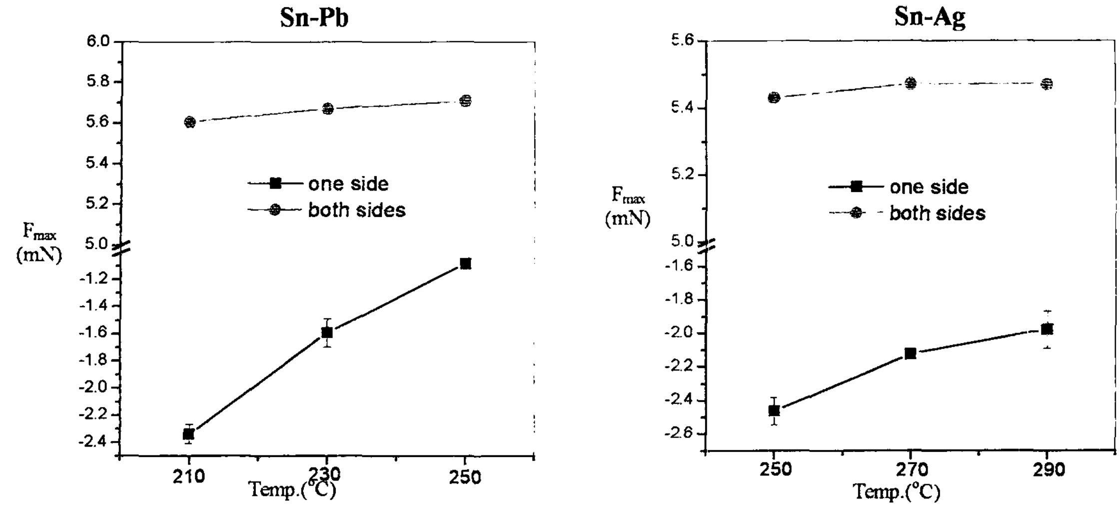

Fig.3. Maximum wetting force of UBM C2(Cr/Cu) for Sn-Pb and Sn-Ag solder

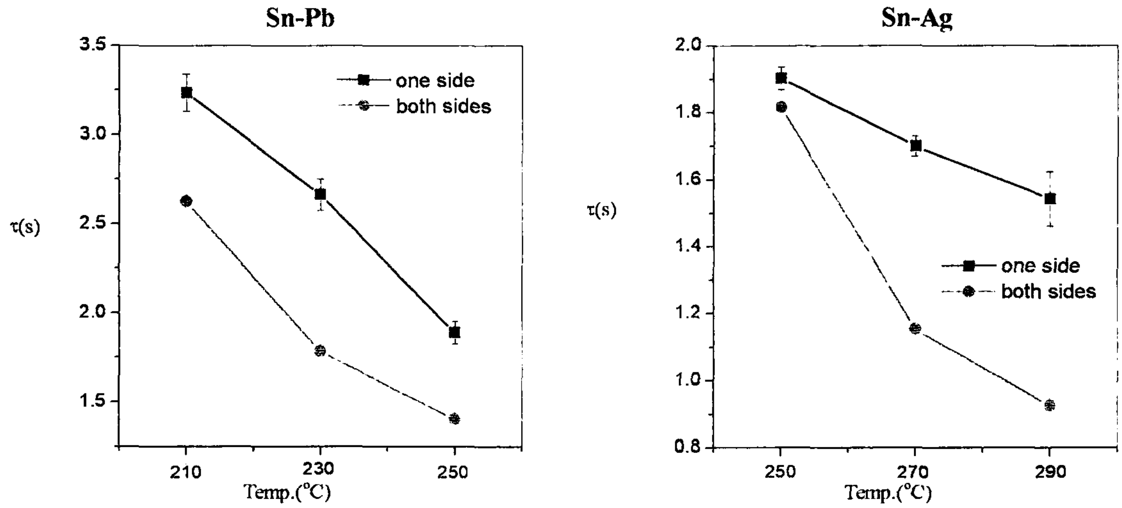

Fig.4. Characteristic wetting time of UBM C2(Cr/Cu) for Sn-Pb and Sn-Ag solder

<Wetting Process & Wetting Indices of One side-coated Specimen>

From the wetting curves of one side coating layer, we can draw the schematic wetting curve of the one side-coated substrate like the Fig. 5. The wetting process consists of 4 stages: (a) immersion of specimen, (b) solder meniscus rising, (c) static state when the meniscus equilibrium maintains, and (d) withdrawal of specimen. In the curve, we chose F_{min}(minimum wetting force), F_s(static state wetting force), and t_s(time to static state) as the new indices to evaluate the wetting properties. F_{min} reflects the buoyancy force plus non-wetting force exerted on non-wettable side right after the immersion. F_s represents the meniscus force by solder wetting. The values of F_{min} and F_s are negative in the wetting curve, so the less their absolute values are, the better is the wettability. t_s is the time to reach static state, that is, meniscus rising time. In addition to these indices, we also measured H, the meniscus height to estimate the wetting properties.

<Wetting Properties of UBM-coated Si-wafer to the Solders>

The F_{min} of UBM-coated Si-wafer is presented in Fig. 6 for Sn-Pb and Sn-Ag solder. The F_{min}s of C1 and C3(Cr/Cu/Au) are larger than that of N1(Ti/Ni/Au). The difference of F_{min} with the Cu layer thickness(C1 and C3) is not so significant. The fact that F_{min} is larger means right after the immersion, less non-wetting force is exerted on the specimen. It should be noted here that the value of F_{min} is negative. So, we can say that C1 has a better wettability than N1.

The F_s of UBM is displayed in Fig. 7. In both solders, the F_s of C1 is larger than that of C3, indicating that C1 is more wettable than C3. F_s of N1 is as good as that of C1 but it is not easy to say which is better in wettability. But when we examine the t_s in Fig. 8, the difference of wetting is obvious. The C1 and C3 have shorter t_s than

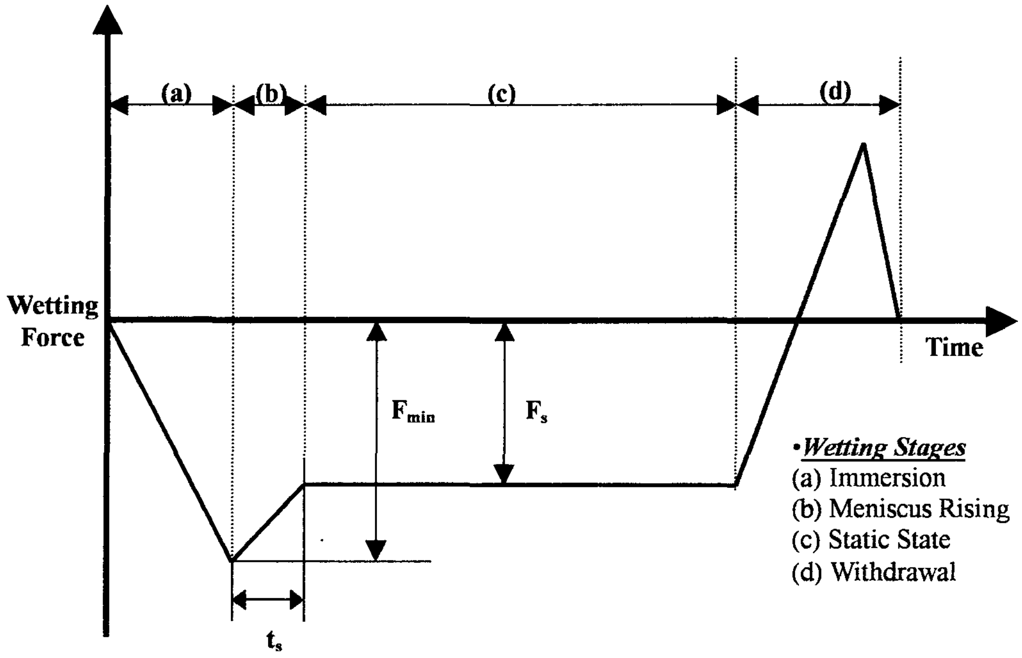

Fig.5. Schematic wetting curve of one-side coated plate and wettability indices

N1 and especially in Sn-Ag solder, C1 has longer t_s than C3. This can explained by relating the facts to the H, the wetting height of solders in Fig 9.

The wetting height of N1 is comparable to that of C1 at the general reflow process temperature(Sn-Pb:230℃, Sn-Ag:270℃). So, the longer meniscus rising time of N1 than C1 means that the wetting progresses more slowly in Ti/Ni/Au than in Cr/Cu/Au UBM. In Sn-Pb solder, the wetting heights of C1 and C3 are within the error range but in Sn-Ag, the wetting height of C1 is higher than that of C3. Hence in Fig. 8, the longer t_s of C1 than C3 implies that the meniscus rose for longer time in C1 than C3.

In brief, as far as wettability is concerned, Cr/Cu/Au UBM is better than that of Ti/Ni/Au from the viewpoint of wetting time. And in Sn-Ag solder C1, which has thinner Cu layer thickness, is more wettable than C3. In other solders such as Sn-Sb, Sn-Bi, and Sn-In, the wetting properties of UBM-coated Si-wafer showed similar tendency like Sn-Ag solder.

In Fig. 9, the wetting properties of UBM C2 with R-type flux is also ploted. For all solders in this work, the wetting properties of C2 with flux is better than the fluxless wetting properties of C1 and C3 which have the Au protection layer. So, it can be said that other treatment to compensate the wettabiliy is necessary such as high purity N_2 reflow, laser or plasma treatment if we guarantee enough wettability between solder and substrate in fluxless reflow soldering.

Fig. 10 shows the F_s and H of UBM for other lead free solders at general reflow temperature. The high melting point solders like Sn-Ag and Sn-Sb has better wettability than low melting point solders such as Sn-Bi, Sn-In and this means that the wetting is limited by thermal demand for Si substrate.

<Static Wetting Force(F_s) and Contact Angle Calculation>

To discuss the effect of specimen tilting of one side coating, we considered the meniscus in equilibrium with molten solder. The static force exerted on the specimen can be expressed as the sum of meniscus force, non-wetting force, and buoyancy force.

Each force can be calculated under the two assumptions. One is that the contact angle at triple point is constant regardless of specimen tilting. The other is that we can apply the Laplace's equation to the meniscus shape of molten solder. With these assumptions, considering meniscus volume, we could obtain the expression of F_s as in equation (1).[3]

$$\begin{aligned} F_s &= w\gamma\cos(\theta-\delta) + 2w\gamma\sin^2\left(\frac{90-\theta+\delta}{2}\right)\tan\delta \\ &\quad - w\gamma\cos^2\delta\tan\delta - w\gamma\cos\xi - 2t\gamma - \rho g V_{buoyancy} \end{aligned} \qquad (1)$$

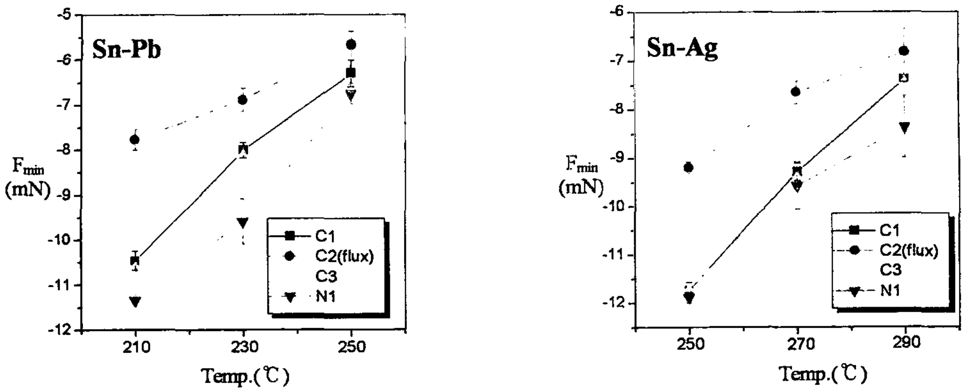

Fig.6. Minimum wetting force of UBM-coated Si-wafer for Sn-Pb and Sn-Ag solder

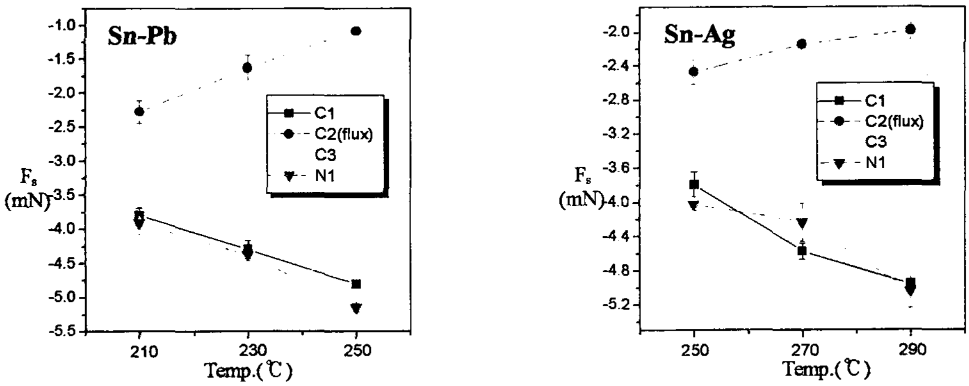

Fig.7. Static State wetting force of UBM-coated Si-wafer for Sn-Pb and Sn-Ag solder

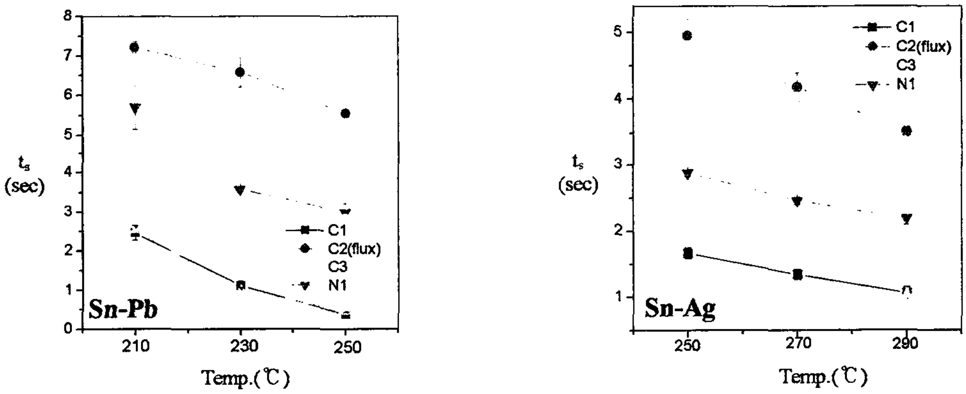

Fig.8. Time to static state of UBM-coated Si-wafer for Sn-Pb and Sn-Ag solder

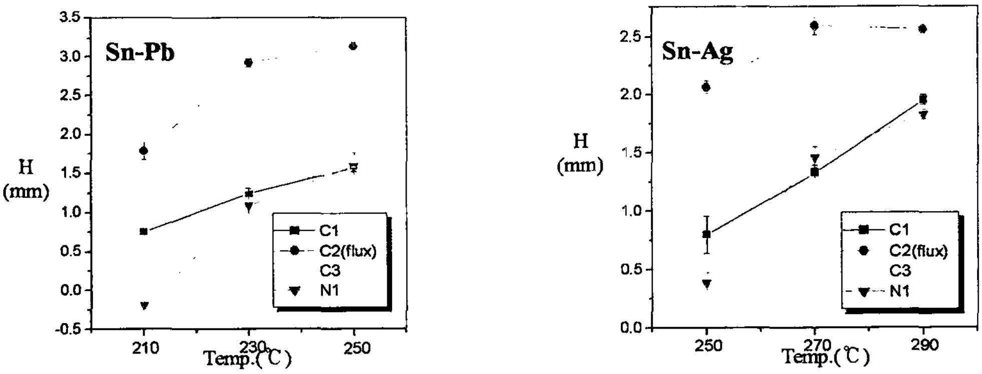

Fig.9. Wetting height of UBM-coated Si-wafer for Sn-Pb and Sn-Ag solder

In equation (1), w represents the width of specimen; γ , surface tension; θ , contact angle; δ , tilt angle; ξ , initial contact angle; ρ , density of solder; V, immersed volume. F_s is a function of tilt angle(δ) and contact angle(θ). Tilt angle is easier to measure than contact angle itself. The contact angle can be calculated in numerical or graphical way by measuring F_s and δ with equation (1).

The contact angles of UBM in Sn-Pb(230℃) and Sn-Ag(270℃) are presented in Table 2. We recall the reported wetting angle for eutectic Sn-Pb on bulk Cu surfaces is 11° in RMA flux at 200℃.[4] So, we can say that the contact angle of 15.8° of UBM C2(Cr500Å/Cu5000Å) with R-flux in Sn-Pb is quite reasonable in this work. But we need further experimental work to get more reliable contact angle data for other UBMs and solders.

Table 2 . Contact Angles of UBM for Sn-Pb and Sn-Ag solder

	C1	C2(flux)	C3	N1
SnPb(230℃)	59.9	15.8	60.9	63.0
SnAg(270℃)	60.7	25.8	64.3	56.6

4. Conclusion

(1) The wetting properties estimation is possible for one side coated-UBM on Si-wafer with the wetting balance method by introducing new indices like F_{min}, F_s, and t_s.

(2) The Cr/Cu/Au UBM has better wetting properties than Ti/Ni/Au UBM especially, in point of witting time. And the Cr/Cu/Au UBM whose Cu layer is 1000Å thick is more wettable than the 5000Å thick-Cu layer UBM.

(3) The high melting point solders like Sn-Ag and Sn-Sb have better wettability than low melting point solders such as Sn-Bi, Sn-In.

(4) The contact angle of the one side-coated UBM can be calculated from the force balance equation by measuring the static state force and tilt angle.

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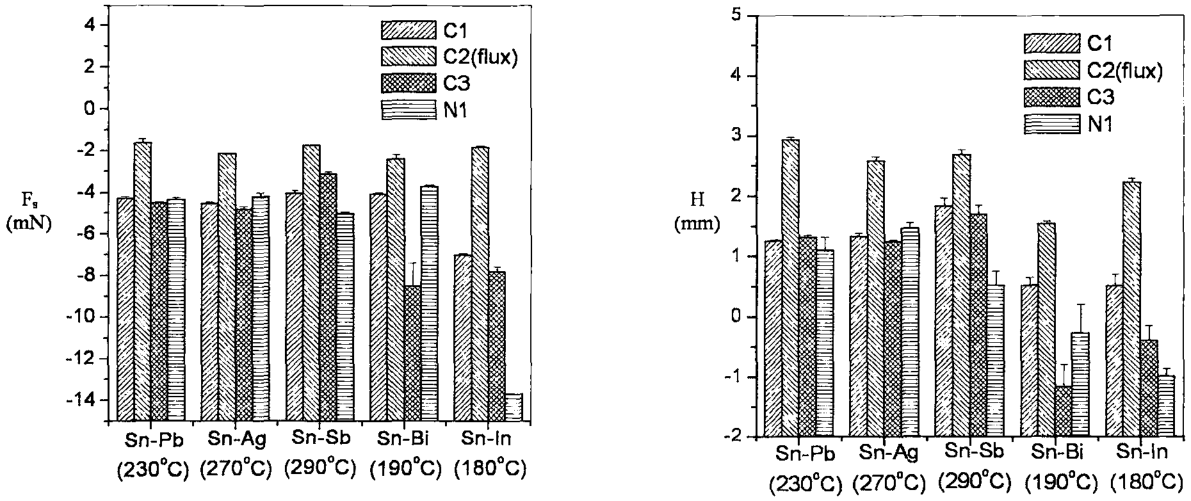

Fig.10. F_s and H for Sn-Pb and lead-free solders