A New Gold-Tin Alloy Composition for Hermetic Package Sealing and Attachment of Hybrid Parts

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Gold-tin eutectic alloys have been widely used in microelectronic applications for a number of years. Of the two eutectic reactions of the gold-tin system, the one which occurs at 80 weight percent gold and 20 weight percent tin has become a sort of industry standard by popular usage. In any application where two gold surfaces are being bonded together with this eutectic alloy composition, the results may not be optimum or trouble-free. Also, the user may not be aware of the available option of selecting another more desirable composition of the same alloy. This article reports on the results of a study of some of the metallurgical characteristics of various compositions of the gold-tin alloy system and recommends that the industry reevaluate its use of the 80-20 gold-tin material.

STUDIES OF THE GOLD-TIN BINARY ALLOY SYSTEM were reported in the literature as early as 1860[1]. R. Vogel reported[2] a study of the entire phase diagram in 1905. References to additional studies are made by M. Hansen[3].

The purpose of a metallurgical phase diagram is to characterize a metal alloy for its crystal structure, solubility, and existence of phases of the constituents throughout a temperature spectrum while the concentration of one of the constituents is varied from 0 to 100%. The concentration is usually reported as atomic percent because this is the preference of the majority of physical metallurgists working in industry. However, most workers in hybrid electronics have learned by experience to use weight percent to define concentration of constituents in the popularly used binary alloys. Interconversion of atomic and weight percent is not difficult and can be accomplished by making use of the following formulas[4]:

$$Y = \frac{100\,(X/A)}{X/A + (100\text{-}X)/B} \tag{1}$$

$$X = \frac{100\,YA}{YA + (100\text{-}Y)\,B} \tag{2}$$

where X = Percentage by weight
Y = Percentage by atoms of an element having an atomic weight A. The atomic weight of the other element in the binary alloy is represented by the letter B.

Equations 1 and 2 may be used with greater ease if rearranged:

$$Y = \frac{100\,X}{X + \frac{A}{B}(100\text{-}X)} \tag{3}$$

$$X = \frac{100\,Y}{Y + \frac{B}{A}(100\text{-}Y)} \tag{4}$$

With this brief introduction to binary alloy phase diagrams, one can begin to enhance his understanding of binary alloy characteristics by spending some time studying the appropriate phase diagrams which are available[3]. Such a diagram is shown in Figure 1. One of the two eutectic points in this alloy system can be identified at 20% wt. of tin. The second eutectic point is at approximately 90% wt. tin. The eutectic temperatures are 280°C and 214°C, respectively. In some way, unknown to this author, the 20% wt. eutectic alloy has become more or less an industry standard brazing or soldering alloy.

About two years ago, a definite yield problem was traced to the processes using 80-20 gold-tin alloy. This material was being used for package sealing and substrate attach. Subsequent investigation and critical evaluation of identified failure mechanisms revealed one common problem related to discontinuous surface wetting of the mating parts. Results of fine leak and gross leak tests on hermetically sealed flat packages reflected extremely critical control of the sealing process in order to maintain acceptable yield levels. This was really the first incentive to launch into a study of the problem. Subsequent X-ray photography of substrate attach using 80-20 gold-tin alloy revealed potentially hazardous voids between the substrate and the gold plated Kovar flat pack base.

Investigation

With these two vivid problems identified, the basic cause also needed to be identified if a reasonable solution were to be found. The hermetic seal failure was studied by mechanically removing lids from flat packs after the normal sealing process and making a microscopic examination of the surfaces. Some evidence was initially found which easily related to contamination on the mating surfaces. The gold plating was burnished and thoroughly cleaned and thermally outgassed in an inert atmosphere just prior to sealing. This eliminated the gross areas of the mating surfaces which did not wet with the alloy melt. However, one type of surface wetting discontinuity still remained evident. Small pyramid or cone shaped alloy structures, each surrounded by some areas of un-wet gold, could be found on one or both mating surfaces. The diameter of the base of these cone structures, where the wetting did occur, usually was about 2.0 to 3.0 micrometers or about .0001 inch. This size corresponds to the topographical irregularities of the gold plated surface. The larger the grain size of the gold plating, the larger the pyramid diameters, but they were still there. One might postulate that the solution would be found in an atomically smooth surface. However, this would reflect a very costly restriction on fabricating the parts. Another important piece of evidence discovered in this flatpack seal study was that the seal surface farthest removed from the heat source exhibited a predominance of pyramid structures while the mating surface closest to the heat source usually wetted in a more continuous pattern.

Interpretation

Assuming that we have learned how to thoroughly clean the seal surfaces and the preforms, we can proceed to establish a model of the gold enrichment of the gold-tin alloy material at or near the melting point of the alloy. Referring again to the gold-tin phase diagram (Figure 1) the liquid phase temperature increases rapidly from the 80-20 eutectic point as gold enrichment occurs. Figure 2 shows an enlargement of this portion of the phase diagram. An increase of 3.5% gold increases the liquid temperature from 280°C to 400°C while 5% more gold results in a liquid temperature of about 450°C. One might ask if this much gold enrichment can actually occur. In order to establish a perspective of the magnitude of gold enrichment, assume that the gold-tin is supplied as a window frame shaped preform with a thickness of .00125 inch. One percent of this thickness is 12.5 microinches. Since the enrichment occurs from both gold plated mating surfaces, the preform needs only to receive 6.25 microinches from each surface to be modified with 1% gold enrichment. With this gold concentration, the liquid temperature has increased from 280°C to 320°C. The effect of gold enrichment on increased liquid temperature as shown in Figure 2 has been correlated to the thickness of gold removed from each of the two seal surfaces in Table I. For convenience, the thickness of absorbed gold has been tabulated in microinches and Angstrom units.

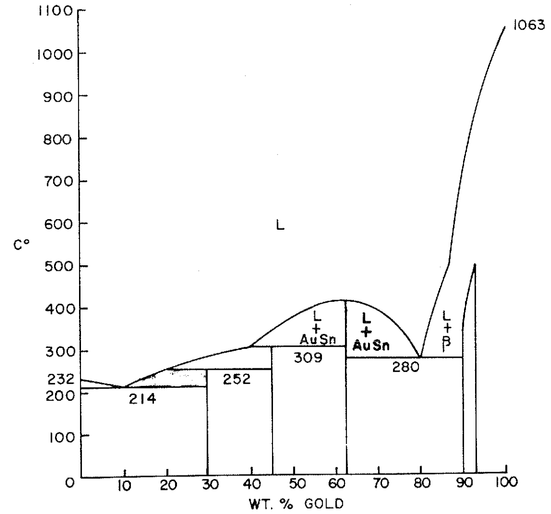

Fig. 1—Phase diagram of gold-tin system.

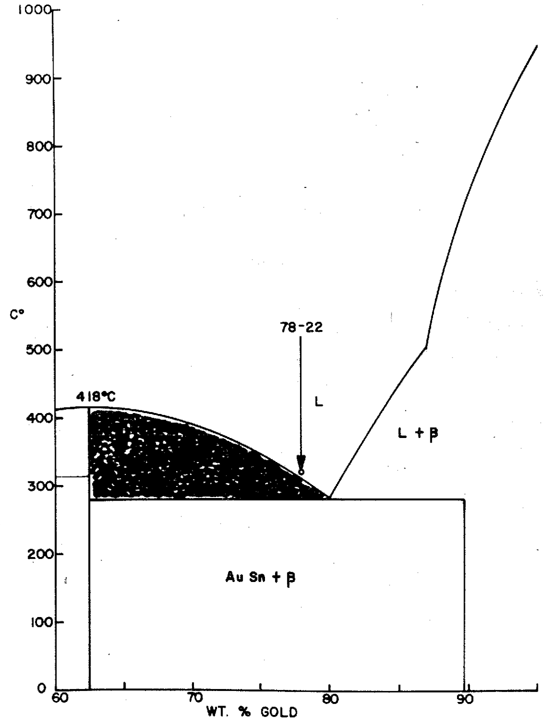

Fig. 2—Expanded portion of Fig. 1 in the area 80 wt. % gold.

Table I—Gold Enrichment of .00125″ Thick 80-20 Gold-Tin Preforms

Percent Enrichment	Liquid Temp.	μ in./ Surface	A/Surface
0	280°C	0	0
1	320°C	6.25	1587
2	350°C	12.5	3175
3	382°C	18.75	4763
4	412°C	25.00	6350
5	445°C	31.25	7938

If this gold enrichment were to be compensated for by tin enrichment in some fashion, then the increased liquid temperature could also be controlled in a limited fashion.

One should also expect the resultant wetting of the mating surfaces to be enhanced because the temperature required to maintain the 78-22 alloy in a liquid state decreases during the time of initial gold enrichment. The decrease continues until the eutectic composition is reached. This is the significant mechanism contributing to the success of good wetting of both mating surfaces and more consistent seals.

The next step in the investigation was to thoroughly clean some 80-20 gold-tin preforms and plate them with pure tin. These preforms were then used to seal some flat packs. The sealing results were successful and exhibited excellent wetting of the gold surface.

Tin plating is an extra process step and might be eliminated if the original alloy constituents were modified to contain more tin and less gold. Further study of the phase diagram (Figure 2) and the metallurgical characteristics of gold-tin in the immediate gold concentration range of less than 80 wt. percent yielded a solution. It is known that gold-tin alloys exhibit an exceptionally high brittleness characteristic except near the extreme ends of the phase-diagram where the malleability of gold and tin become predominate because both these metals in the pure state have a ductile lattice structure. Thus brittleness raises the question of whether it is possible to roll and punch preforms with a little more tin or does the alloy brittleness prevent it. Alloys were formulated from 70% gold to 78% gold at a commercial plant using production preform fabrication methods. Fabrication yields were about 12% with a 70% gold alloy due to brittleness, but at 75% gold, the yield increased to about 20%. However, shipping these tiny parts presented a potential problem because they were significantly more brittle than the 80-20 ones. Seal tests, using 75-25 alloy preforms, resulted in excellent yields and very good wetting. Finally, a composition of 78% gold-22% tin was thoroughly evaluated. Preform fabrication was little or no more of a problem than making 80-20 preforms. A comparison was made of the helium mass spectrometer fine leak test results for three groups of flat packs, all sealed under the same conditions except for the preform gold-tin alloy composition. The alloy compositions had gold-tin weight percents of 80-20, 78-22, and 75-25 respectively. The leak rates for the 80-20 group ranged from 0.8 to 2.0×10^{-8} cc/sec. while the rates for the other two groups were in the range from 0.3 to 1.0×10^{-8} cc/sec. This indicates an increase by a factor of at least two in seal effectiveness when the preform is tin enriched by 2% to 5% from the gold-tin eutectic composition.

Some microcircuit hybrid designs specified 80-20 gold-tin alloy for attaching substrates to packages and attaching certain semi-conductor chips to the substrate. In each case, the mating surfaces were gold. Substitution of 78-22 ment significantly. An example of this improvement was shown in an X-ray study of the substrate attachment. An X-ray television instrument such as that used in quality control inspection was used to view through the sealed flat package assemblies. Small variations in gold thickness could be readily detected on the CRO display as distinct variations in transmission contrast. Photographs were taken of these X-ray displays for various flat pack substrate attachment samples using 80-20 gold-tin preforms and 78-22 gold-tin preforms (Figure 3). The light gray tone indicates voids between the substrate and the bottom of the flat pack where the wetting and the flow of the preform material has not occurred (Figure 3a, b). This is typical of the consistent problem experienced with 80-20 gold-tin alloy. Typical experience with 78-22 gold-tin alloy preforms for substrate attach gives the results shown in Figure 3c and d. The black area along the perimeter of the substrate in Figure 3c is excess preform material which came out from under the substrate during attachment reflow. This is the result of using a preform slightly larger than optimum.

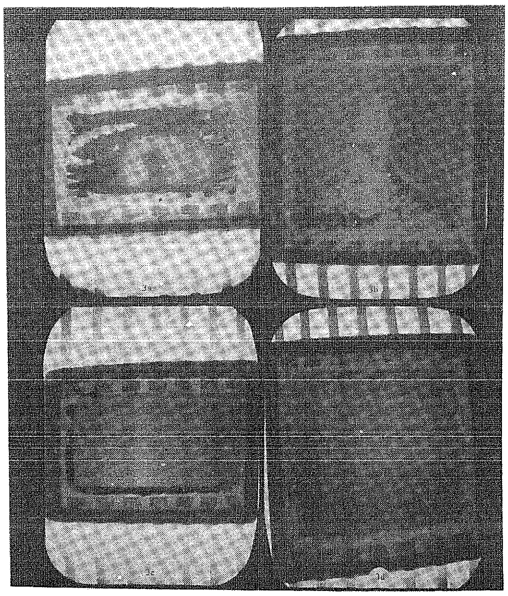

Fig. 3—X-ray photos of gold-tin alloy substrate attach in flat-packs. (a) and (b) show voids between substrate and package; (c) and (d), no voids.

Conclusions

The intent of this report is to provide some evidence from which the hybrid microelectronics industry can begin to re-evaluate the use of 80-20 gold-tin alloy and consider the substitution of 78-22 gold-tin composition. The immediate advantages, in the opinion of the author, are product improvement, high yields and thus lower production costs without sacrificing present techniques and processes. Preform procurement should not present any difficulty, but actually result in a slight cost reduction with less gold content in the preform material. For the user of solder creams instead of preforms, the manufacturers who have been contacted reported that they would supply the 78-22 alloy on the same basis as that on which they now supply the 80-20 gold-tin.

References

1. A. Matthiessen, Pogg, Ann., **110,** 1860, 214-215.
2. R. Vogel, *Z. Anorg. Chem.,* **46,** 1905, 60-75.
3. M. Hansen, "Constitution of Binary Alloys," McGraw-Hill, 1958, 232-234.
4. From C. S. Smith, *AIME Contribs.,* no. 60, 1933.