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1. Introduction

In step with the recent microminiaturization of multimedia and information equipment, electronic microcomponents and their packaging technology are playing a key role in hardware product development and production technology.

The development of electronic apparatus are led by the progress of device packaging technologies. For example, BGA (ball grid array types of package) and CSPs (chip scale packages) were adopted as soon as the limits of TAB (tape automated bonding) were exceeded by the advent of multi-pinned and narrow-pitched QFPs (quad flat packages).

Senju Metal Industry is prepared to provide a total soldering system, utilizing the research and development of soldering materials (such as solder spheres), technique review and application of high quality and reliability standards ministering to diverse packaging technology.

This paper deals with a method of mounting these devices onto a mounting board (base), provides related solder ball technical information, and introduces related soldering material products.

Trend of device packages

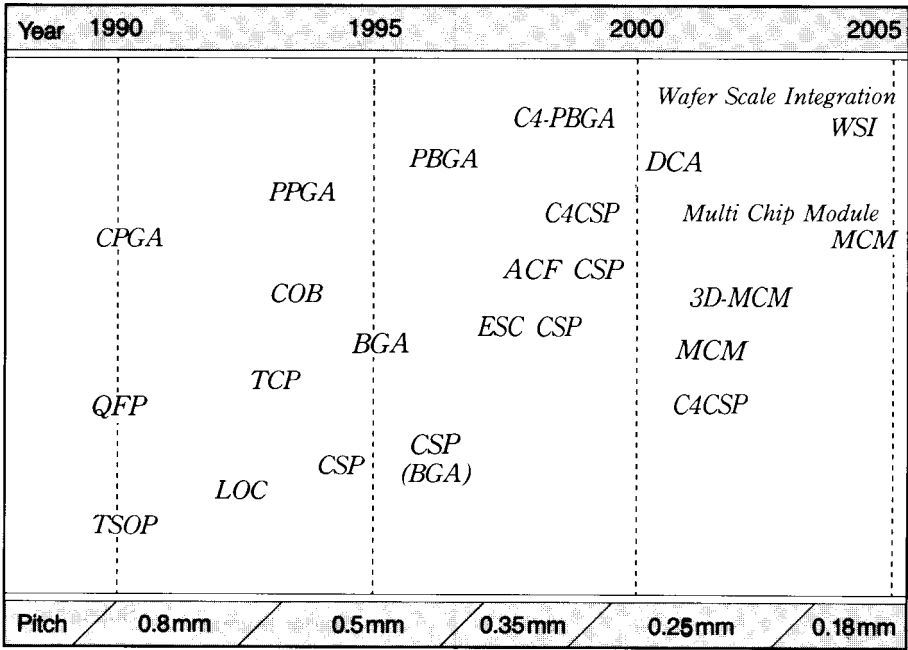
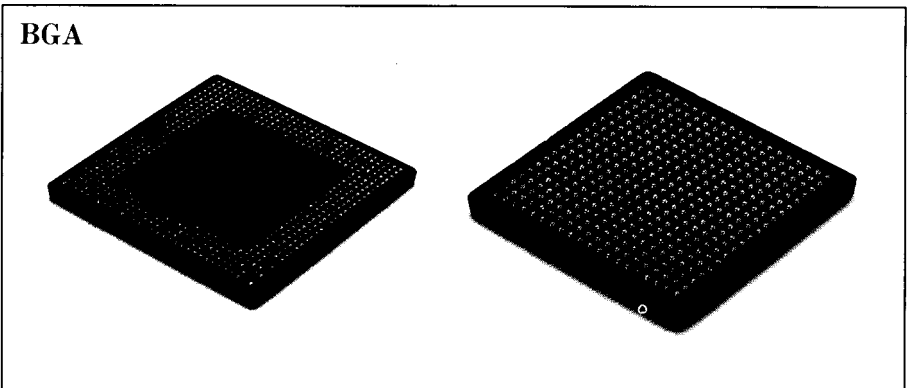


Fig.1 Trend of device packages



2. Types of BGA/CSP Package.

The following diagram illustrates the structures and features of representative packages using solder sphere technology.

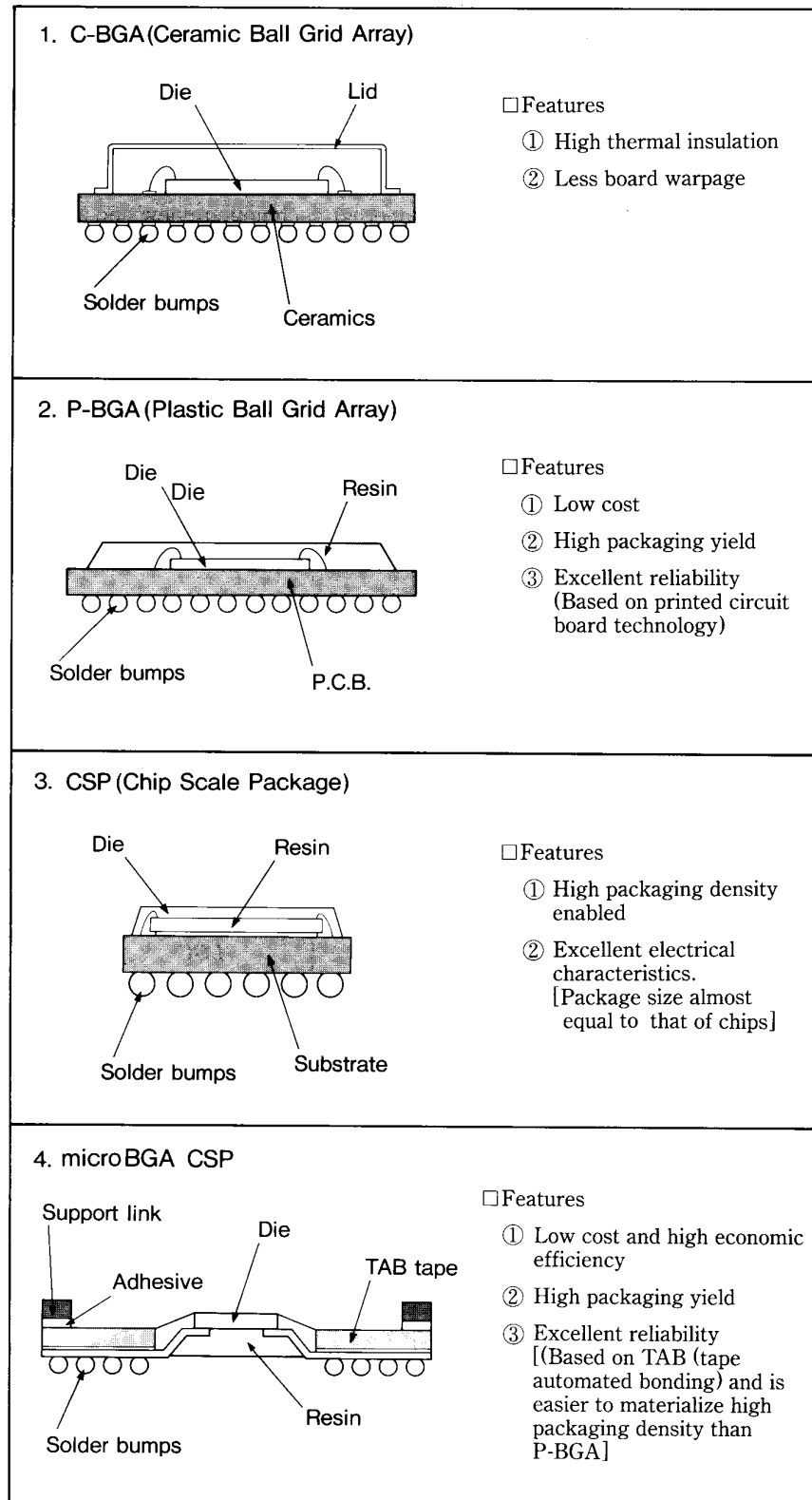


Fig.2 Device packaging systems

3. Solder Balls

[1] SPARKLE® BALL solder balls.

Senju Metal Industry Co., has been manufacturing high purity solder balls (Sparkle Balls) and supplying them to the electronic industry for over twenty years. The Sparkle Ball allows a uniform supply of solder in definite quantities ministering to the needs of semiconductor and electronic component suppliers and has been widely used for soldering electronic components such as; bumps (electrodes) of hybrid ICs and power transistors, quartz oscillators, and diodes.

In recent years, land grid array types of LSI packages with a two-dimensional array of pad electrodes have been merchandised in place of conventional semiconductor packages with an array of lead pins, such as BGAs (ball grid arrays), CSPs (chip scale packages), and MCMs (multichip modules). This recent trend has been creating a fresh demand for solder balls to be used as bumps of the pads of those LSI packages. Solder balls have also been used as bump electrodes for Flip Chips.

Still, we are building even tighter quality control systems to control the entire process. These controls follow from research and development to manufacturing lines in order to meet the accuracy and cleanliness requirements of the newer semiconductor products.

(1) Product specifications.

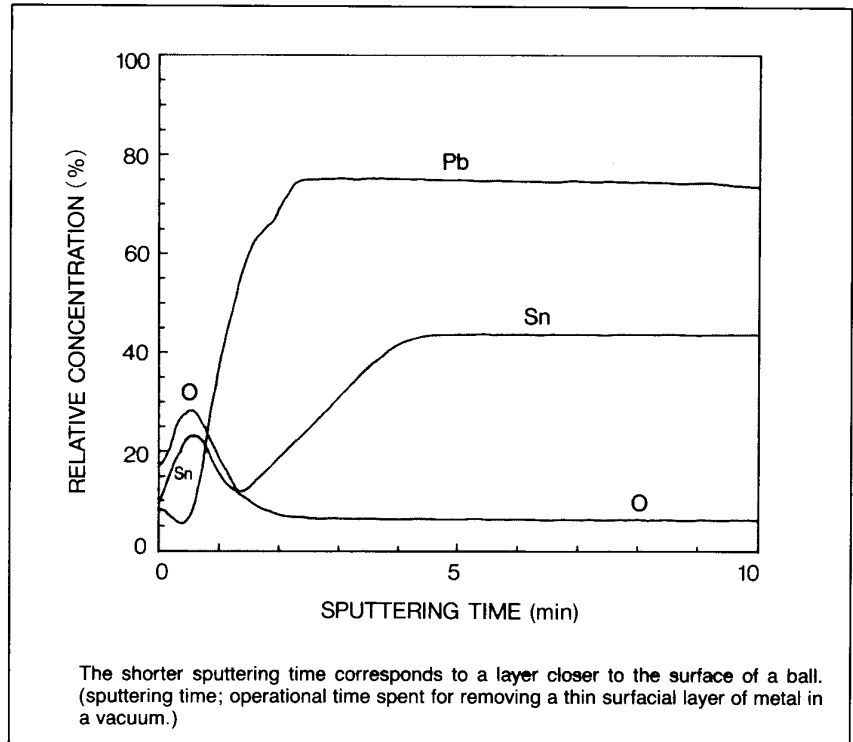
The SPARKLE BALL is manufactured using various solder alloys including the most common eutectic (Sn63 Pb37). Senju also manufactures spheres using proprietary fatigue-proof and lead-free solder alloys, from which each user can select according to the application. (See Table 3. "Representative examples of Sparkle Ball alloy compositions")

(2) Features of SPARKLE BALL.

The surfacial irregularity of solder balls could pose a problem with handling performance requirements or a pick up in the packaging process. To cope with this problem, the SPARKLE BALL is so manufactured as to be free from surfacial damage (flows, scratches, etc) or irregularities. We are also manufacturing solder balls almost immune to surfacial oxidation or contamination through quality control strict enough to secure the required cleanliness and finish of the surfaces. Figure 3 shows the results of measurements of oxide film formed on the surface of the SPARKLE BALL by Auger electron spectroscopy.

Table 1 lists the results of measurements of oxidation on a zirconia dioxide sensor.

Surface of ball and surfacial oxidation issues.



**Fig.3 Measurements surfacial oxide layers
(by Auger electron spectroscopy)**

Measuring and analyzing oxidation values.

Table 1. Results of measuring and analyzing oxidation values (by zirconia system.)

Product's Item [Alloy composition & Ball size (mm)]	Oxidation value (ppm)
SPARKLE BALL Sn63 ϕ 0.76	8.4
SPARKLE BALL Sn10 ϕ 0.70	7.1

[Zirconia system: measurement on zirconium oxide type oxygen concentration sensor]

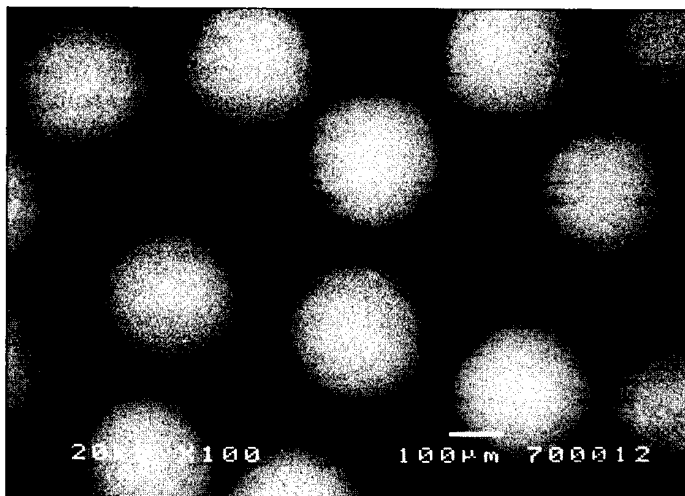


Fig.4 SPARKLE BALL

(3) Particle size distribution and sphericity distribution.

The JEDEC (Joint Electronic Device Engineering Council) Standard recommends a maximum of 0.15mm, or 0.006 inch, as the copularity of 0.76mm diameter solder ball applied packages. The dimensional tolerance required by this standard specification is generally $\pm 20 \mu\text{m}$, but $\pm 10 \mu\text{m}$ for high-level ones. It is needed to take into account problems with the accuracy and warpage of each board whenever a dimensional tolerance is determined for a particular ball. [See "SPARKLE BALL Specifications" on page 7 for dimensional tolerances.]

Figure 5 shows several examples of particle size distribution for representative SPARKLE BALL products. The data provided here has resulted from measuring balls manufactured at a dimensional tolerance of $\pm 10 \mu\text{m}$.

Particle size distribution.

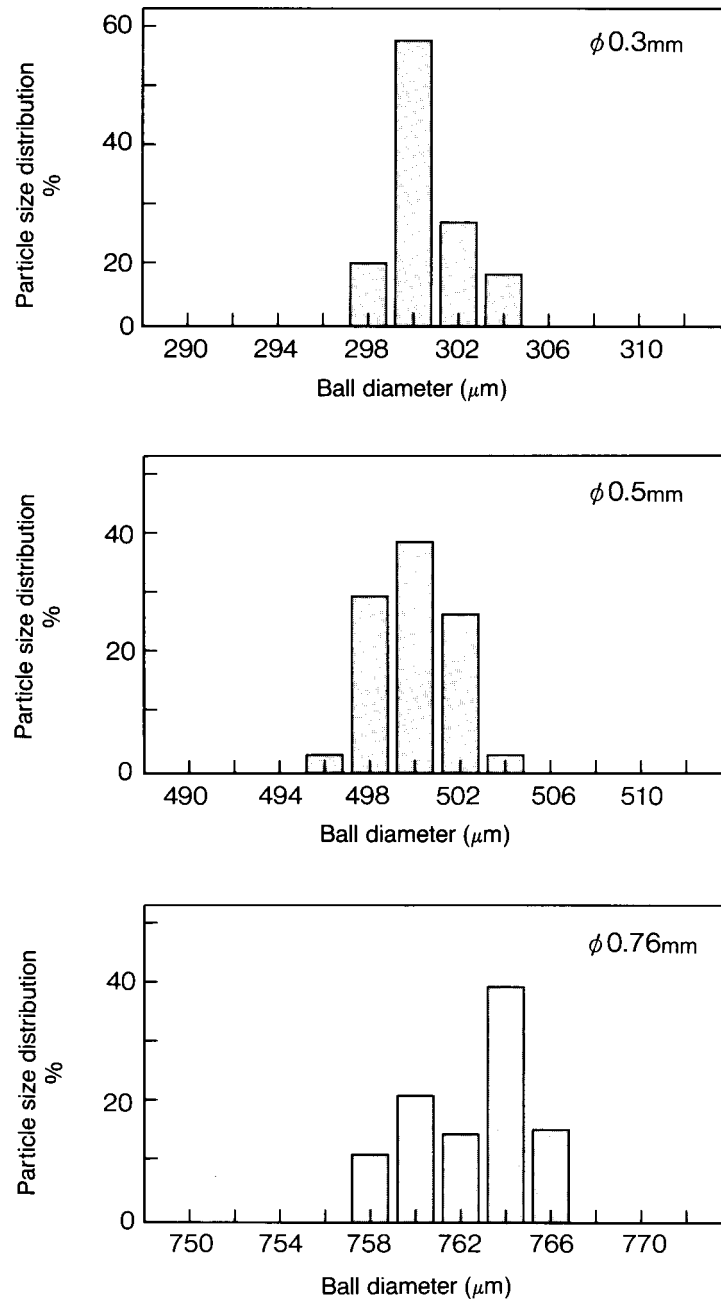


Fig.5 Particle size distribution of SPARKLE BALL

Since the required accuracy in sphericity of solder balls depends on the system of each manufacture's mounting machine, there seems to be no movement towards official standardization as yet. The sphericity of the SPARKLE BALL falls within 1.5% in terms of sphericity determined by the following expression:

$$\text{Sphericity (\%)} = |A-B| \div \{(A+B) \div 2\} \times 100$$

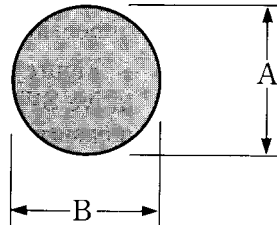


Fig.6 Sphericity measuring sides

Figure 7. shows examples of sphericity distribution determined by the above expression for representative SPARKLE BALL products. The data provided here has resulted from measuring balls manufactured at a dimensional tolerance of $\pm 10 \mu m$.

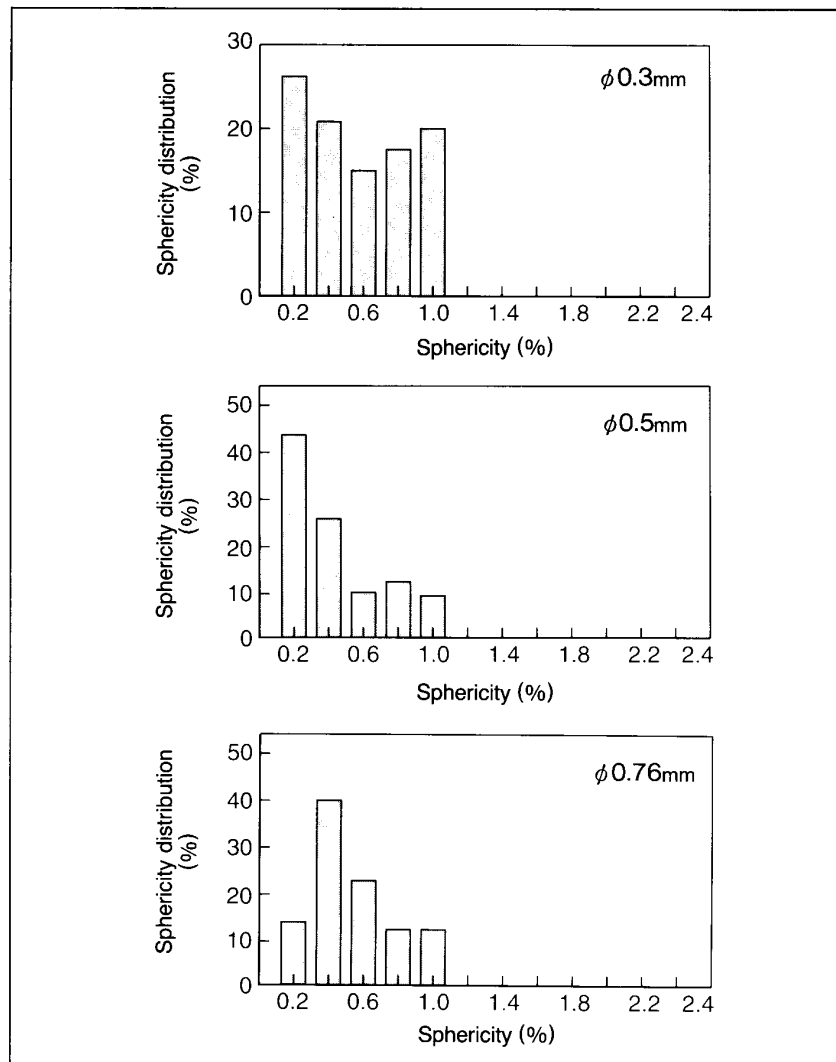


Fig.7 Sphericity distribution of SPARKLE BALL

(4) Addressing "Voids".

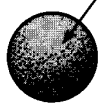
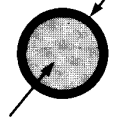

The occurrence of a void in a solder ball can create failures in the solder joint by lowering the strength of the joint.

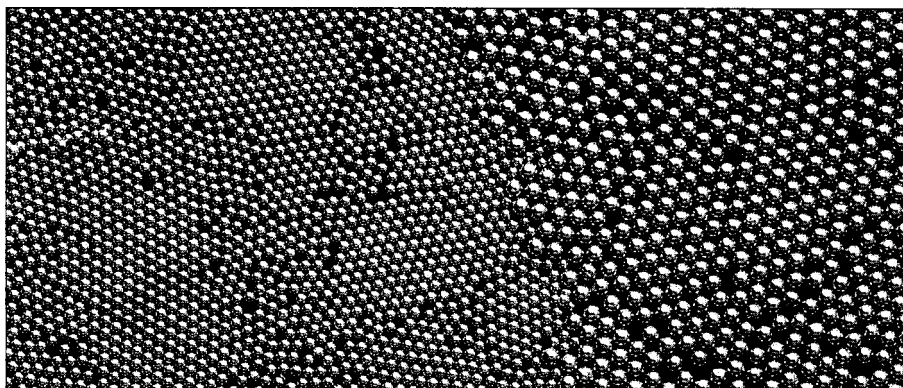
The SPARKLE BALL products made by applying our original techniques are finished free from voids in balls, so they enable highly reliable bonding.

[3] Types of SPARKLE BALL.

The SPARKLE BALL is largely divided into three types according to specification and structure. The S type is most widely used for BGA and CSP packages.

Table 2. SPARKLE BALL Specifications

Typification	Form	Core	Diameter (ϕ mm)	Features
S Type	 Spherical		0.1 above ~ 0.2 under	Diameter deviation is within ± 0.005
			0.2 above ~ 0.76 under	Diameter deviation is within ± 0.010
			0.76 above	Diameter deviation is within ± 0.020
C Type	 Solder plated Ag, Cu ball	Ag	Ag cored ball: 0.3 ~ 0.6	Diameter deviation is within $\pm 20\mu\text{m}$.
		Cu	Cu core dia.: 0.25 ~ 0.70 Thickness of solder plated: ~ 50 μm	Diameter deviation is within $\pm 10\mu\text{m}$ under 0.3 ϕ . Diameter deviation is within $\pm 20\mu\text{m}$ above 0.3 ϕ .
Pure metal ball	 Spherical		0.1 above	Sn, Pb, In, etc.



[4] Alloy Compositions of SPARKLE BALL.

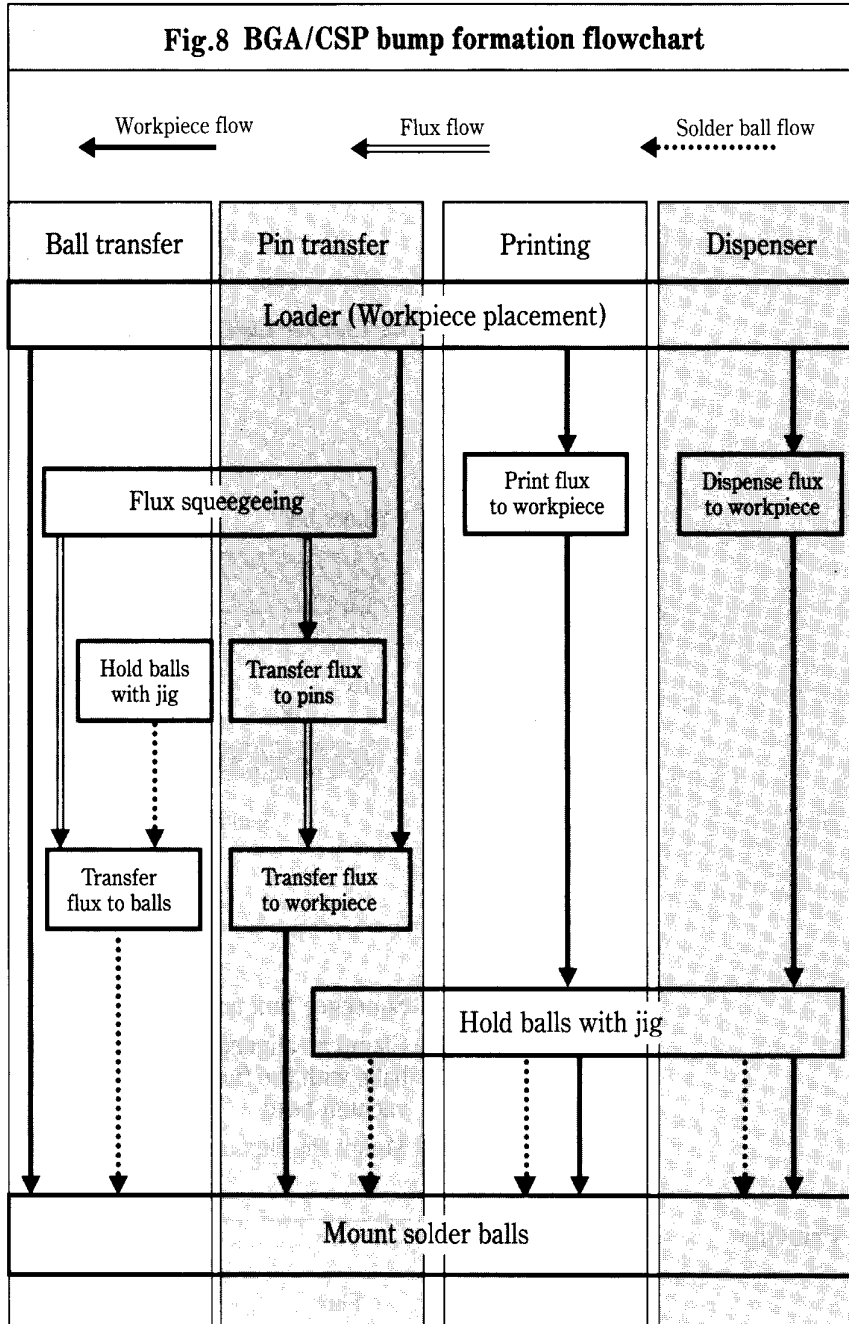
There are various types of solder alloys with the SPARKLE BALL.
Table 3 lists its representative products.

The Sn63 Pb37 and S2062 alloys are most widely used for solder
sphere applications.

Table 3. Typical SPARKLE BALL alloys

Product's Item	Characteristics	Alloy composition	Melting temperature (°C)		Specific gravity
			Solidus	Liquidus	
Ordinary solder	H5	Sn5-Pb	300	314	11.0
	H10	Sn10-Pb	268	301	10.7
	H63	Sn63- Pb	183		8.4
Silver bearing solder	S-2062	Ag2-Sn62-Pb	178	192	8.4
	S-356	Ag3.5-Sn60-Pb	178	232	8.5
	S-1505	Ag1.5-Sn5-Pb	294	326	11.0
Low temperature solder	# 130	In-Sn-Pb	130		7.8
	# 139	Sn-Bi	139		8.7
	# 150	Sn-Bi-Pb	135	152	9.4
	# 165	Sn-Bi-Pb	135	165	9.1
High temperature solder	#220	Ag-Sn	221		7.4
	#240	Sn-Sb	235	240	7.3
	#295	Ag-Sn-Pb	285	296	10.9
Indium bearing solder	6001	In-Pb	173	221	8.9
	6013	In-Pb	172	190	8.5
	6014	In-Ag-Pb	147	228	7.9
Thermal fatigue-resistant solder	9025	Sn-Pb	183		8.4
	7050	Sn-Ag-Pb	178	210	8.4
Lead-free solder	6047	Sn-Ag-Cu-In	210	214	7.4
	7027	Sn-Ag-Cu	216	220	7.4
	7046	Sn-Ag-Bi-Cu	189	214	7.5

[5] Typical BGA • CSP bump formation.



4. Flux Application Techniques.

[1] Process Techniques.

Figures 9, 10, 11, 12 show examples of representative techniques for mounting balls onto a package. See "Appendix" on page 20 for information about fluxes as connective materials corresponding to the respective techniques.

Ball transfer

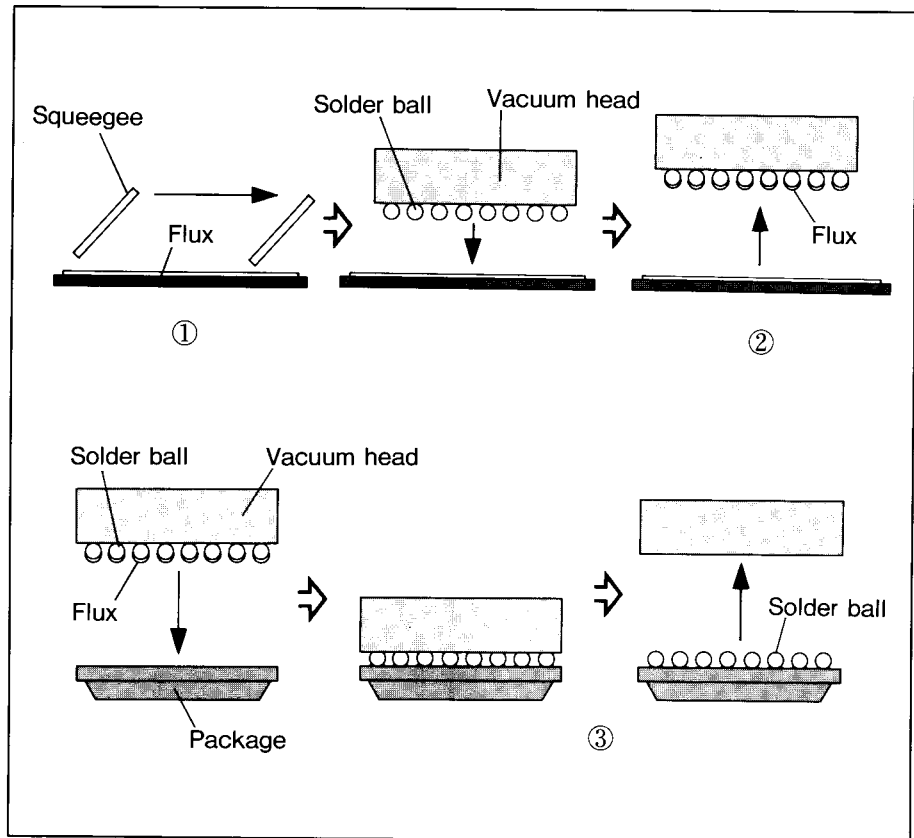


Fig.9 Ball transfer

- 1) Squeegee flux uniformly.
- 2) Clamp an aligned array of solder balls on the vacuum head, contact the balls with the flux surface, transfer the flux uniformly, and lift up the vacuum head.
- 3) Mount the flux-transferred solder balls onto the board side of a package.

Printing

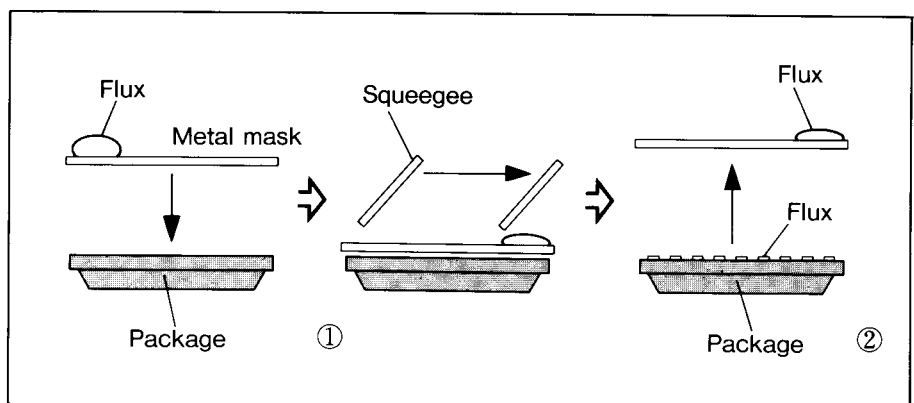


Fig.10 Printing

- 1) Feed flux to a package by printing with a squeegee.
- 2) Mount balls onto the flux-printed side. Then mount the solder balls.

Pin transfer

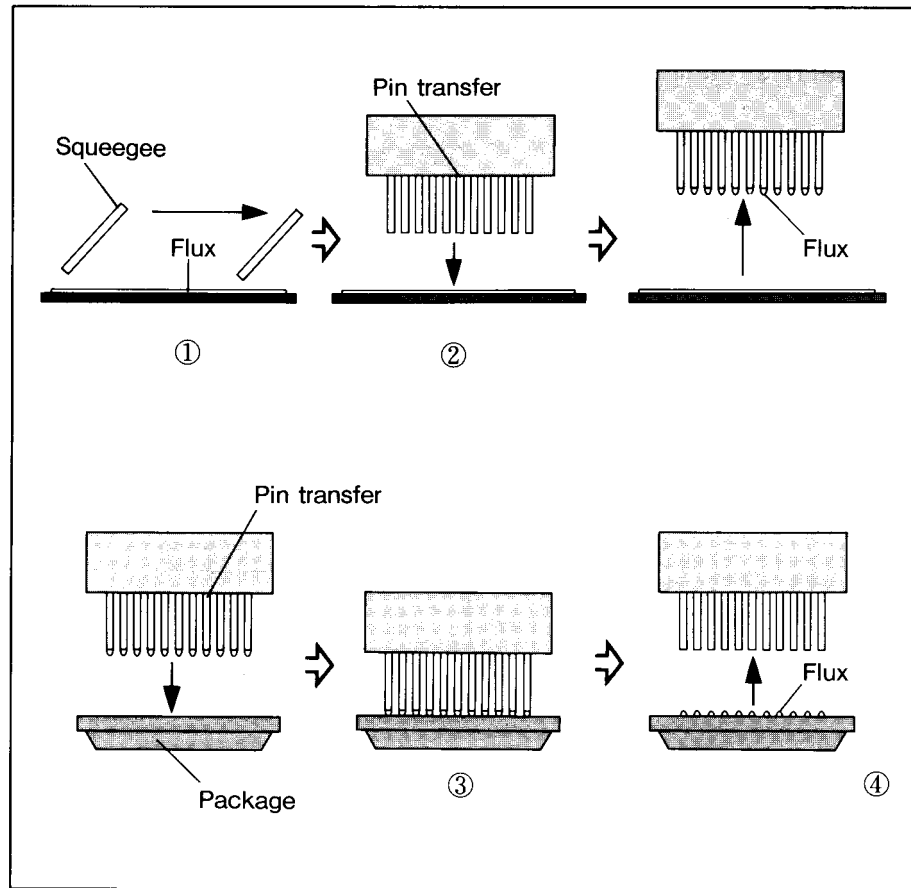


Fig.11 Pin transfer

- 1) Print flux uniformly.
- 2) Contact the pin transfer with the printing side and transfer the flux.
- 3) Attach the flux-transferred pins to the board side of a package and transfer the flux uniformly.
- 4) Clamp an aligned array of solder balls on the vacuum head, and mount the balls onto the flux-printed region.

Dispenser

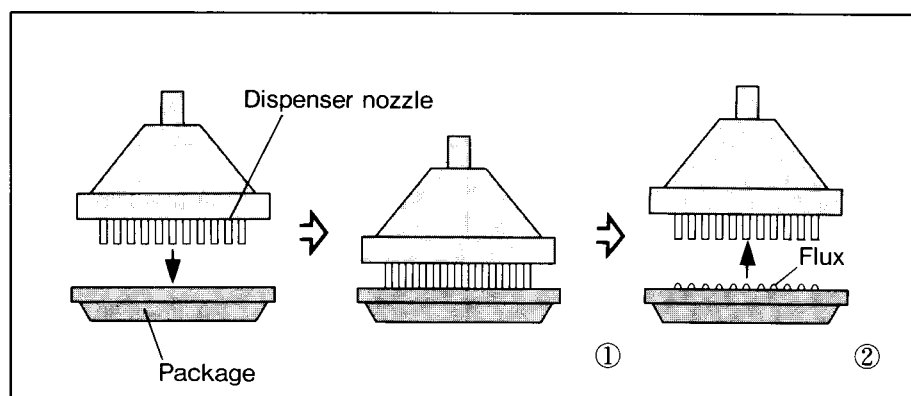


Fig.12 Dispenser

- 1) Uniformly apply flux to a package through a multinozzle.
- 2) Align and vacuum solder balls on the vacuum head and mount the balls onto the flux-applied regions.

5. Notes on Use of SPARKLE BALL

[1] Spherical diameter, volume, and weight of SPARKLE BALL.

Table 4 lists representative examples of the spherical diameter, volume, and weight of a single Sn63-Pb ball. See the Table on page 19 for the other sphere diameters.

Table 4. Spherical diameter, volume, and weight of each Sn63-Pb Ball.

Spherical diameter (mm)	Volume (mm ³)	Weight (mg)
0.30	0.01414	0.1188
0.50	0.06545	0.5498
0.76	0.22985	1.9307

These numeric values are determined by the following expression:

$$\text{Weight} = \text{Specific gravity} \times (4/3)\pi \times (\text{Spherical diameter} / 2)^3$$

The weight and size of each solder alloy other than those listed in Table 4. above can be calculated by applying this expression to data in Table 3. "Representative examples of SPARKLE BALL alloys."

[2] IC packages and Solder ball sizes.

There are various kinds of packages in which spherical solder is used as electrode bumps, which are largely grouped into three: flip chip, CSP and BGA. Table 5 lists the representative particle diameters of solder balls applied to these types of packages.

Table 5. Types of package and applied ball sizes

Types of package	Ball diameter (mm)	Tolerance (μm)	Component standard
Flip Chip	$\phi 0.10 - 0.20$	± 5 ± 10	Conforming to JIS 23282 Class S
CSP	$\phi 0.30 - 0.50$	± 10 ± 20	Conforming to JIS 23282 Class S
BGA	$\phi 0.50$ above	± 20	Conforming to JIS 23282 Class S

Table 6. Japanese Industrial Standard: JIS Z 3282S

Metal Elements	Sn	Pb	Impurity (wt %)							
			Sb	As	Cu	Fe	Zn	Bi	Cd	Al
Class S	62~64	Remains	0.1 max.	0.03 max.	0.03 max.	0.02 max.	0.002 max.	0.03 max.	0.002 max.	0.002 max.

Table 7. lists common solder ball diameters corresponding to land pitch sizes available for IC packages.

Table 7. Ball diameters corresponding to land pitches (reference values)

Pitch size (mm)	Corresponding ball dia. (mm)
1.27	$\phi 0.90$
1.00	$\phi 0.76$
0.80	$\phi 0.50$
0.50	$\phi 0.30$

[3] Ball alignment.

Techniques for aligning solder balls on the surface of a package are different from manufacturer to manufacturer. The following introduces two representative processes.

Ball pickup system.

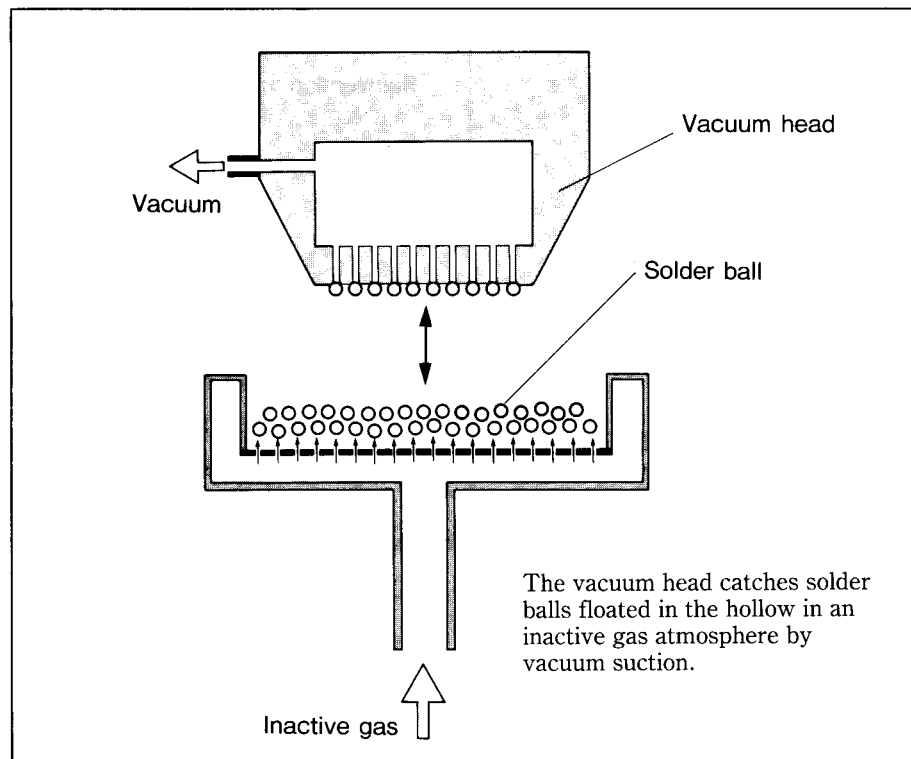


Fig .13 Ball pickup system – (1)

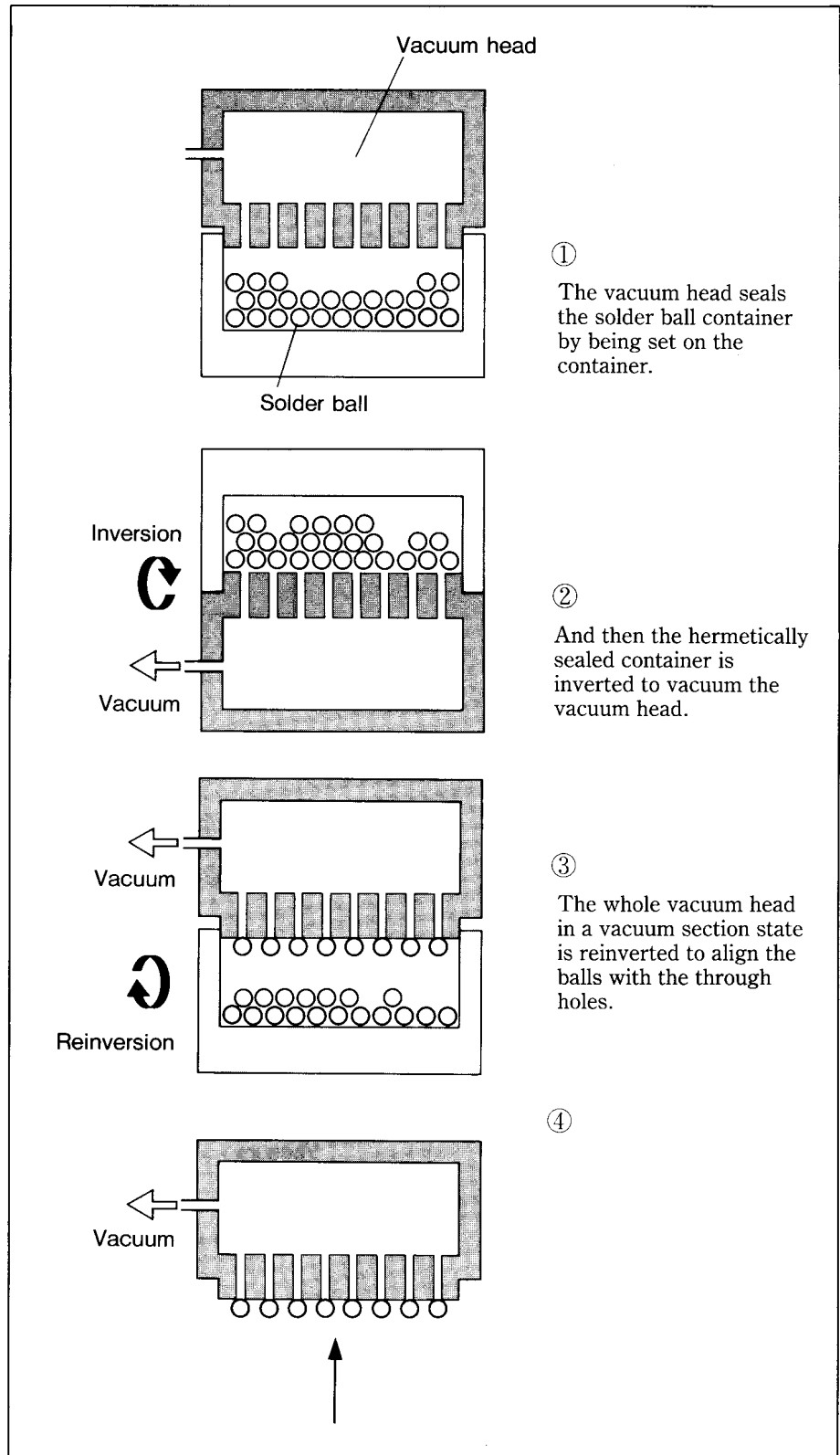


Fig.14 Ball pickup system (2)

[4] Reflow conditions [recommended].

When solder balls are mounted and soldered onto a package, the reflow conditions (heating temperature, heating time, and temperature rising speed) produce a marked effect on the finish state of solder bumps. Figure 15 is a reflow temperature profile of mounted and packaged components.

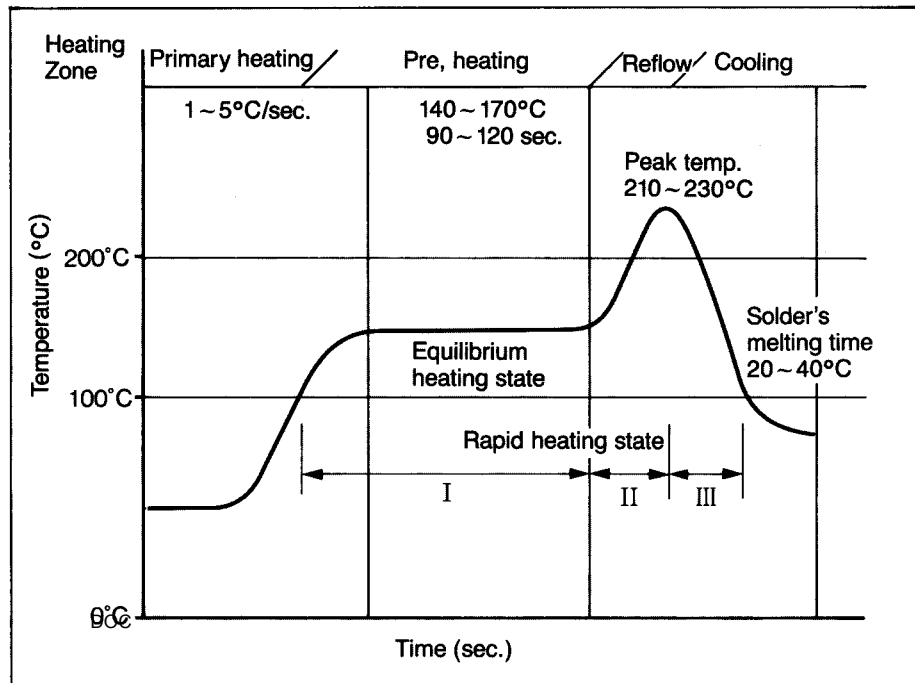


Fig.15 Sn63-Pb recommendation reflow profile.

Improper reflow conditions might cause the following defects in each of zones I to III:

- (I) Misalignment: No balls are present. Two or more balls are clustering.
- (II) Insufficient wetting: Only a certain part is soldered.
- (III) Defective appearance: Poor glossiness. Wrinkles are present. Imprecate patterns are developing. Uneven flux brushing. Sink marks are present.

A misalignment in zone I may occur frequently with convection reflows, so it is recommended to use an SX reflow furnace in parallel with a panel heater. The most marked effect of reflow conditions on packaged boards or mounted components is considered to be caused by the cooling speed in zone III. These factors necessitate due examination of reflow condition setting. In this respect, it is better to use a N₂ (nitrogen atmosphere) reflow furnace in order to give a good finish to solder wetting and appearances.

[5] Blackening symptoms.

The surfaces of solder balls may blacken because of surfacial oxidation due to rubbing against one another during ball mounting. (Effect of rocking at a ball pickup time) Rocking solder balls may increase the amount of oxidation or cause a change in surfacial state, with the result of degraded quality.

The progressive surfacial oxidation of solder balls might cause a defect, such as mirror balls, after reflow because of the failure of solder balls to be reduced enough. This symptom will be improved in a N₂ atmosphere. Since the surfaces of solder balls need to be clean from the outset, we have adopted a system capable of supplying solder balls of high surfacial cleanliness.

Figure 16 and 17 show results of a comparative analysis of changes in ball surface state due to solder ball rocking.

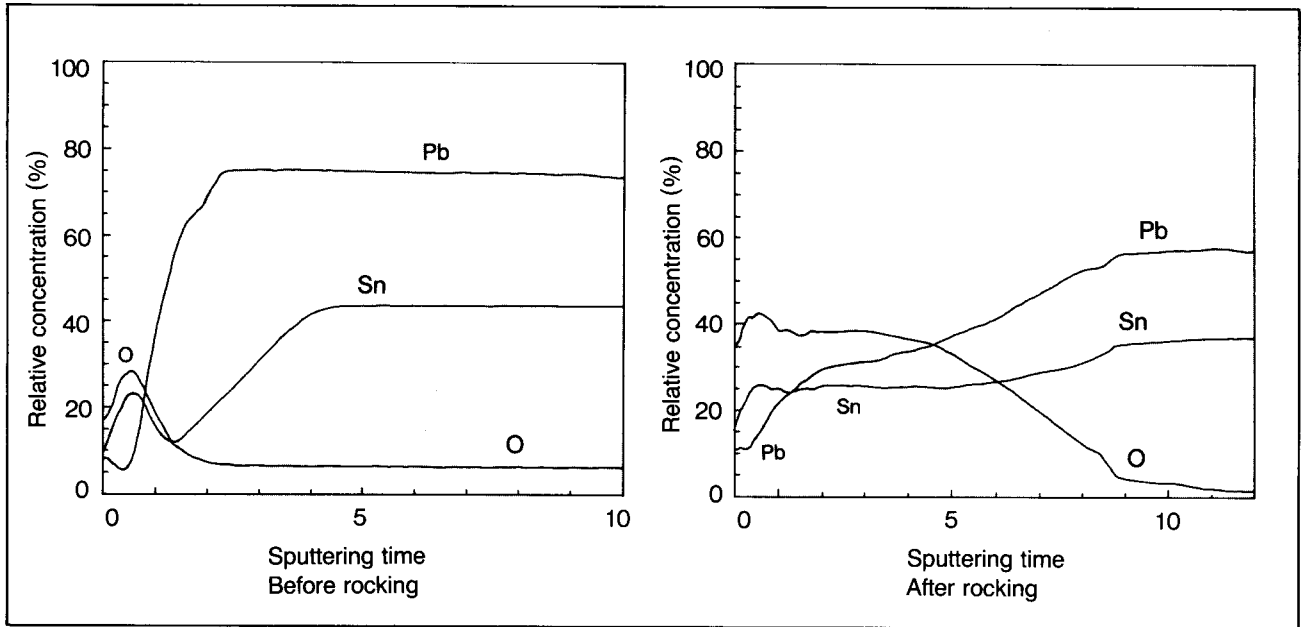


Fig .16 Results of analysis of solder ball surfaces before and after rocking

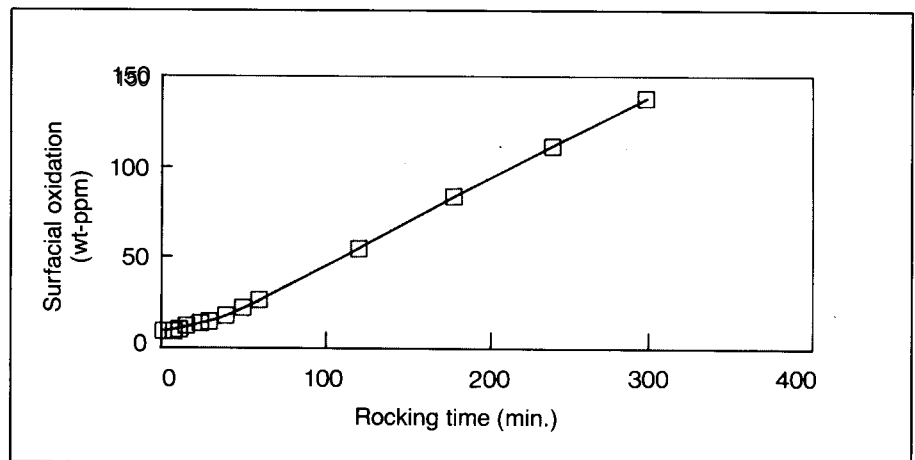


Fig .17 Correspondence of solder ball rocking time to change in amount of surfacial oxidation

[6] Countermeasures against static electricity.

Solder balls, being fine and spherical, are easy to move so they may be charged with static electricity when stored in glass containers. However, glass containers provide very good protection against oxidation. Therefore, most users find the glass containers most practical for their application.

Because of this concern regarding electrified balls being used in some kinds of mounting machines, Senju has developed special ESD (Electro Static Discharge) containers for those customers requiring static protection.



Related data [1].

Packaging of SPARKLE BALLS.

Argon gas has been sealed inside the glass containers to keep the surface of the Sparkle Ball clean. For countermeasures against static electricity, contact our business office for information, as these containers conform to separate specifications.

*The guarantee period for Sparkle Balls enclosed in glass bottles sealed with Argon is one year from the date of manufacture.

Table 8 lists criteria in determining the number of balls to be packaged in a single container in relation to ball diameter, ball count, and container size.

Table 8. Maximum number of packaged balls in relation to container size

Container \ Ball	Ball dia. (mm) and number of balls contained			
	$\phi 0.76$	$\phi 0.50$	$\phi 0.30$	$\phi 0.10$
5cc	-	-	-	5,000,000
10cc	-	-	250,000 Standard packaged	10,000,000
30cc	-	-	500,000	-
50cc	100,000	-	-	-
100cc	250,000 Standard packaged	500,000 Standard packaged	-	-
200cc	500,000	-	-	-

Appendix Related Data [2]

Recommended fluxes for use with respective techniques

Table 9. Volume and Weight of the Sn63 Pb37 solder sphere in relation to spherical diameters

H63: Spherical diameter, Volume & Weight		
Spherical dia. (mm)	Volume (mm ³)	Weight (mg)
0.10	0.00052	0.0044
0.20	0.00419	0.0352
0.30	0.01414	0.1188
0.40	0.03351	0.2815
0.50	0.06545	0.5498
0.60	0.11310	0.9500
0.63	0.13092	1.0998
0.65	0.14379	1.2079
0.70	0.17959	1.5086
0.72	0.19543	1.6416
0.76	0.22985	1.9307
0.80	0.26808	2.2519
0.90	0.38170	3.2063
1.00	0.52360	4.3982
1.20	0.90478	7.6001

Appendix Related Data [3]

Recommended fluxes for use with respective techniques.

Fluxes for use with respective techniques [I]: Resin family (recommended)

Techniques	Pin transfer	Ball transfer	Dispenser	Printing
Products	DELTA LUX	DELTA LUX	DELTA LUX	DELTA LUX
Characteristics	529D	533	527N	523
Phase	Paste	Paste	High viscous liquid	Paste
Flux type	RMA	RA	RMA	RMA
Solid content (at %)	60%	67%	70%	68%
Chlorine content	0.002 under	0.002 under	0%	0.002 under
Viscosity	15Pa.s	10Pa.s	16Pa.s	130Pa.s
Spreadability	80%	90%	86%	85%
Corrosion test on copperplate	Passed	Passed	Passed	Passed
Insulation resistance (<i>ohm</i>) the normal condition	1014 above	1012 above	-	1014 above
after 96hr. in a thermo-hygrostat regulated	1012 above	1010 above	109 above	1012 above

Fluxes for use with respective techniques [II]: Water soluble type (recommended)

Techniques	Pin transfer	Ball transfer	Dispenser	Printing
Products	Sparkle Flux		Sparkle Flux	Sparkle Flux
Characteristics	WF-6030	-	385	WF-6020
Phase	Paste	-	High viscous liquid	Paste
Solid content (wt %)	69%	-	84%	57%
Chlorine content	100ppm below	-	-	20ppm below
Viscosity	85Pa.s	-	140Pa.s	54Pa.s
Spread ability	-	-	80% above	-
pH	4.4	-	4.3	5.4
Tackiness Initial (gf)	50 above	-	-	50 above

SMIC

SENJU METAL INDUSTRY CO.,LTD.
TOKYO JAPAN

•**Head Office:**

Senju Hashido-cho 23, Adachi-ku, Tokyo 120-8555, Japan Phone'
(81) 3-3888-5151 Telefax' (81) 3-3870-3032

•**Sales Office:**

Hanamaki / Akita/ Sendai / Kohriyama/Takaoka/ Suwa/ Nagoya /
Osaka/Fukuoka

•**Works:** Tochigi/Saitama/Tokyo/Hyogo

•**Laboratories:** Tochigi/Saitama/Tokyo

Overseas Affiliates:

Europe

•**SATO EXPORT & IMPORT GmbH.**

0-40211 Dusseldorf, Germany

Phone' (49) 211-35 70 14 Telefax' (49) 211-16 1191

•**SENJU MANUFACTURING (EUROPE) LTD.**

High Wycombe, Bucks HP12 3PY, England

Phone: (44) 1494-439-786 Telefax' (44) 1494-526-222

North America

•**SENJU AMERICA INC.**

Great Neck, New York 11021, U.S.A.

Phone' (1) 516-82 95 488 Telefax: (1) 516-82 91020

•**SENJU COMTEK CORP.**

San Jose, California 95112, U.S.A.

Phone' (1) 408-792- 3830 Telefax: (1) 408-792 3838

Asia

•**SENJU (MALAYSIA) SON. BHD.**

40000 Shah Alam, Selangor, Malaysia

Phone' (60) 3-511 2227 Telefax: (60) 3-511 2428

•**SENJU TRADING (M) SON. BHD.**

40000 Shah Alam, Selangor, Malaysia

Phone: (60) 3-511 6670 Telefax: (60) 3-511 2814

•**SENJU SOLDER (PHILS) INC.**

Rozario, Cavite, Philippines

Phone: (63) 96-971-0236 Telefax: (63) 96-437-8719

China

•**SENJU METAL (HONG KONG) LIMITED.**

Suite 1401, World Commerce Center, Harbour City, Kowloon, Hong

Kong Phone' (852) 23763319 Telefax' (852) 23 7631 19

•**SENJU SOLNET METAL CO., LTD.**

On Rok Tsuen, Fanling, N.T. Hong Kong

Phone: (852) 26 82-22 35 Telefax' (852) 26 82-2271

•**TANGSHAN SENJU METAL INDUSTRY CO., LTD. Tangshan City**

063030, Hebei Province P.R. China

Phone' (86) 315-32 37 914 Telefax' (86) 315-32 37 924

•**BEIJING SENJU ELECTRONIC MATERIAL CO., LTD. Chaoyang**

District, Beijing, 100016 P.R. China

Phone' (86) 10-64 38 91 31 Telefax: (86) 10-64 38 91 35

Agency

* Contact us for samples on additional details.