APPLICATION NOTE

Surface Preparation for Wire Bonding

By David Jackson

Introduction

Shown in Figure 1 is a typical wire bonding procedure. To ensure bondability and reliability of wire bonds, one of the critical conditions is that the bonding pad surface must be free of contaminants (1). Therefore bond pad cleaning is an important process prior to wire bonding.

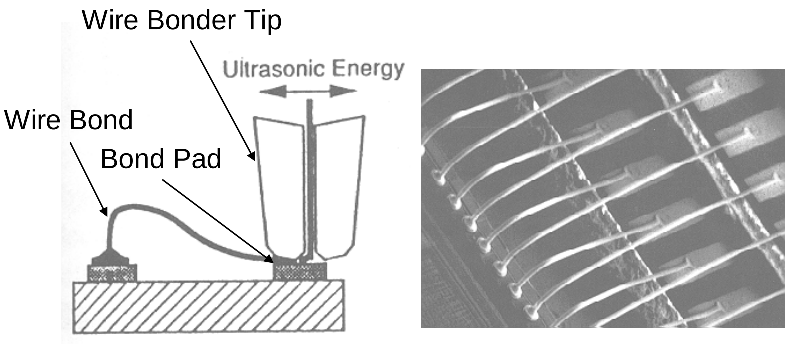

Fig. 1. Wire bonding operation

Selective CO_2 spray cleaning technology offers a robust and flexible technique for achieving cleanliness on bond pads. A bond pad can be made very clean and wettable by removing residues, particles and activating the surface.

Bond Pad Contamination

Surface contaminations are a major cause of the loss in the bondability and the reliability of wire bonds. The contaminants that have been found to degrade bonds are shown as following:

- Halogens and Hydrocarbons: plasma etching, epoxy outgassing (dry processing), photoresist strippers, cleaning solvents (i.e., TCA, TCE).
- Contaminants from plating operations: thallium, brighteners, lead, iron, chromium, copper, nickel, hydrogen.
- Sulfur: packing containers, ambient air, cardboard & paper, rubber bands.
- Miscellaneous organic contaminants: epoxy outgassing, photoresist, general ambient air (poor storage), personnel.
- Others that cause corrosion or inhibit bonding: sodium, chromium, phosphorous, bismuth, cadmium, moisture, glass, vapor, nitride, carbon, silver, copper, tin.

Application Note AN1001

CLEANLOGIX

In addition, there are many human sources of contamination, such as small particles of skin, hair, sweat, spittle, and mucus. These may arrive at the device surface by talking, coughing, sneezing yawning, head shaking, and scratching. These also include cosmetics, hand lotions, facial make-up and fibers from clothing. A person sitting motionless generates about 10^5 particles per minute of greater than 0.3 µm in diameter. This number increases exponentially with movement.

A fully suited person, walking in a class 100 clean room, will distribute 50,000 particles in that same period of time. Other sources of contamination may be entrained in the air as hydrocarbons and ions such as Cl- and Br-, or outgassed from cleaned clothes (i.e. dry cleaning solvents).

As can be seen, there are many sources of contamination that may challenge a wire bonding operation which must be removed to insure reliable and strong bonds.

CO_2 Cleaning Evaluation

Background

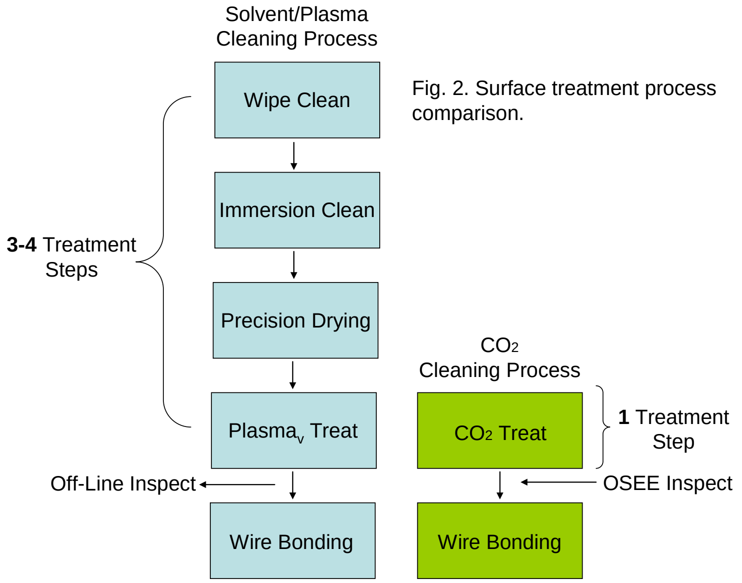

Fig. 2. Surface treatment process comparison.

A major U.S. defense contractor was seeking to improve the efficiency, reliability and selectivity of its gold ribbon bonding operation for a critical missile defense system. Shown in Figure 2, the previous surface treatment process utilized a proprietary combinational cleaning process comprising; 1) manual solvent wipe cleaning (i.e., Acetone), 2) immersion cleaning, and 3) Ar/O_2 vacuum plasma treatment. This required an operator to perform two or more process steps in separate steps. Technical problems associated with the previous bond pad cleaning process included smearing and re-deposition of contaminant residues that accumulate or entrain within the wiper and solvent, and an inability of vacuum plasma treatment to reliably remove various inorganic residues and particulate matter from the bonding pads. Moreover, inconsistencies in applying the manual cleaning process introduced variability into the bond pad cleaning process. Finally, the previous process was not selective. The entire electronic assembly was immersed in, and contacted with, cleaning agents, which introduced precision drying and cross-contamination challenges.

A statistically significant evaluation was performed to determine the effectiveness of an alternative CO_2 surface treatment as a comparison to their current cleaning process (2). As shown in Figure 2, the new CO_2 process would provide a much simpler and dry surface treatment process. Moreover, a new on-line non-contact bond pad inspection technique evaluation was included in the evaluation as a means for establishing surface cleanliness criteria for wire bonding operations. The Optically Stimulated Electron Emission (OSEE) technique would allow the CO_2 cleaning and wire bonding operation to occur in sequence, or even within the same workcell, and without the need for an off-line statistical surface evaluation (current procedure).

The experimental testing and results are summarized and discussed below.

Experimental

To determine the cleaning effectiveness and bond pull characteristics of the new CO_2 process in comparison to the previously established surface preparation method, 106 ceramic substrates (Al_2O_3), designated as sample numbers SN1-SN106, each containing a surface layer of metal vapor deposit comprising TiW, Ni and Au, were divided into 4 test groups. These composite substrates represent the bonding pad characteristics of the actual electronic boards in various states of cleanliness, described as follows.

Solvent/Plasma Cleaning Process Test Group (SN1-5, SN16-20, SN31-35, SN45-50 and SN85-89)

25 samples, designated as SN1-5, SN16-20, SN31-35, SN45-50 and SN85-89, were subdivided into 5 sample sets, contaminated as described below and cleaned using the existing process described above.

CO_2 Cleaning Process Test Group (SN6-15, SN21-30, SN36-45, SN51-60, and SN90-99)

25 samples, designated as SN6-15, SN21-30, SN36-45, SN51-60 and SN90-99, were subdivided into 5 sample sets, contaminated as described below and cleaned using the new CO_2 cleaning process described below.

Surface Contamination Challenge

Both the Existing and New CO_2 process test groups (50 sample coupons) were doped using a brush with a particular contaminant type as follows:

- Tape Adhesive (SN1-15)
- Finger Oils (SN16-30)
- Flux (SN31-45)
- Silicone Oil (SN46-60)
- Combination of adhesive, finger oils, flux and silicone oil (SN85-99)

Each type of contamination was brushed onto the surfaces using an acetone solvent carrier and dried.

Note: The simulated surface contamination is a very thick film which is visible with unaided light inspection. This type of contamination is not considered to be a normal bond pad contamination level and thus represents a worst-case scenario. More importantly, an artifact is introduced in the challenge test. The application of the various challenge contaminants to the bonding surface also contaminates the non-bonded surfaces of the test coupons, with some wicking of contaminant to the underside surfaces of the test coupons. Given this, the comparison between the current cleaning process (i.e., a total immersion process) with the new CO_2 cleaning process (i.e., a selective spray treatment) introduces variability in the certain aspects of examination. In particular, higher levels of residual contamination were expected and observed on selectively treated coupons during testing due to unavoidable sidewall and underside contamination. Therefore, the OSEE bonding surface analysis results, bond pull data and statistical analysis of same represent the more significant results in this investigation.

OSEE Baseline Test Group (SN61–65)

5 samples (SN61-65) were retained for establishing a baseline photocurrent for a new non-contact surface inspection method called Optically Stimulated Electron Emission (OSEE), described below. The OSEE photocurrent of the OSEE baseline testing group was compared to the contaminated and CO_2 cleaned coupons.

Bonding Parameter Test Group (SN101, SN102, SN101-105)

7 samples, SN101, SN102, SN101-SN105, were used to establish the ribbon bonding and pull test criteria for all test groups.

Control Group (SN66-84, SN106, SN100)

A total of 21 samples, designated as SN66-84, SN106 and SN 100, were retained as sample controls. Following metalization processes, control samples were vacuum plasma treated (see description above), ribbon bonded and pull tested to establish a baseline bond pull test.

CO_2/OSEE Spray Test Apparatus

Shown in Figure 3, the CO_2 snow spray treatment and testing apparatus comprised a programmable cartesian robot with moveable x, y and z axes. Connected to the z-axis is a treatment fixture having a coaxial snow spray applicator and an OSEE surface measurement probe. Test coupons were affixed to the x axis, whereupon a computer program executed a sequence to move the treatment head from side-to-side (y axis) and up and down (z-axis).

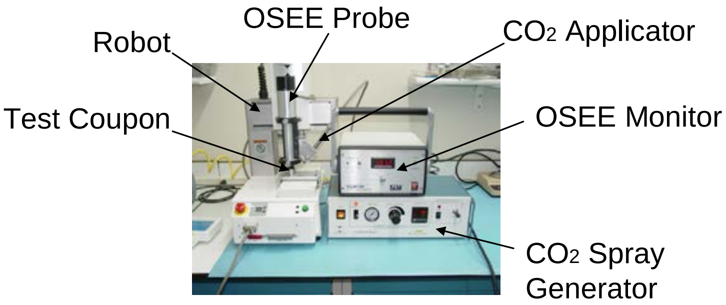

Fig. 3. CO_2/OSEE test apparatus

CO_2 Cleaning Process Metrics

Propellant:

Type:	Nitrogen Gas
Pressure:	80 psi (552 kPa)
Temperature:	120° C (393 K)

Snow:

Cap. Diameter (I.D.):	0.030 inches (8 mm)
Cap. Length:	8 feet (244 cm)
Applicator Nozzle:	Coaxial Green 2:2 Straight
Spray Angle:	45 Degrees

Plasma: (Utilized in Commercial System Only)

Treatment Gas:	Carbon Dioxide
Type:	Atmospheric
Spray Pressure:	80 psi (552 kPa)
Spray Angle:	90 Degrees

Robot/Hybrid Treatment Applicator:

Robot Type:	Cartesian, 3-axis
Treatment Scanrate:	10 mm/sec (adjustable)
Treatment Sequence:	Snow only
Distance from surface:	1.27 cm (adjustable)

CO_2 Cleaning Method: (Referring to Figure 4)

1. Operator mounts test substrate onto robot mounting fixture.
2. CO_2 snow is sprayed at test substrate using a robot scanning procedure.

3. Operator removes treated parts from mounting fixture.

Fig. 4. Before/After CO_2 Treatment (Coupon 096)

Process Description:

CO_2 snow is sprayed over the entire topside surface of the test sample, simulating the actual application which comprises two (2) strips of gold bonding bonds. The topside contamination area treated comprised approximately 2 inch x 1 inch (5 cm x 2.5 cm) portion of a 2 inch x 3 inch (5 cm x 8 cm) test substrate. A total of three (3) treatment passes were performed on each strip.

Ribbon Bonding

The gold wire bonding equipment is shown in Figure 5 and the process parameters are described as follows:

Ribbon Bonder:	Westbond Model Number 4630E
Bonding Au Ribbon:	0.005” x 0.007”
Ribbon Bonding Tool:	Deweyl MRCSVD-1/16-1-52-CG-.5X7-M

Ribbon bonding was performed with tool heat and work holder temperature at 150° C. Following bonding, all wirebonds were pull tested using a procedure detailed in MIL-STD-883E (3).

Fig. 5. Wire bonding apparatus

OSEE Inspection

Optically Stimulated Electron Emission (OSEE) is a unique technique for non-invasive analysis of surfaces for molecular contamination (5). This technique utilizes a tool which utilizes ultraviolet radiation to create electron emission from a surface, resulting in a small current detected by the tool. Electron emission is dependent on the substrate's surface chemistry; hence the electron emission characteristics will change with the presence of a contaminant on the surface, generally by attenuating the signal.

Fig. 6. OSEE SQM 100 Monitor

OSEE testing was performed prior to and following CO_2 cleaning tests for test coupons, designated as SN6-15, SN21-30, SN36-45, SN51-60, and SN90-99, described above. The OSEE test equipment, shown in Figures 3 and 6, comprised the following elements:

1. Photoemission Analyzer, Surface Quality Monitor, Model No. SQM100.

2. Photoemission Sensor, Model No. 60262.

Results and Discussion

Bond Pull Failure Modes; Number of Bond Lifts

Control Group:	0
Solvent/Plasma:	10
CO_2 Snow:	6

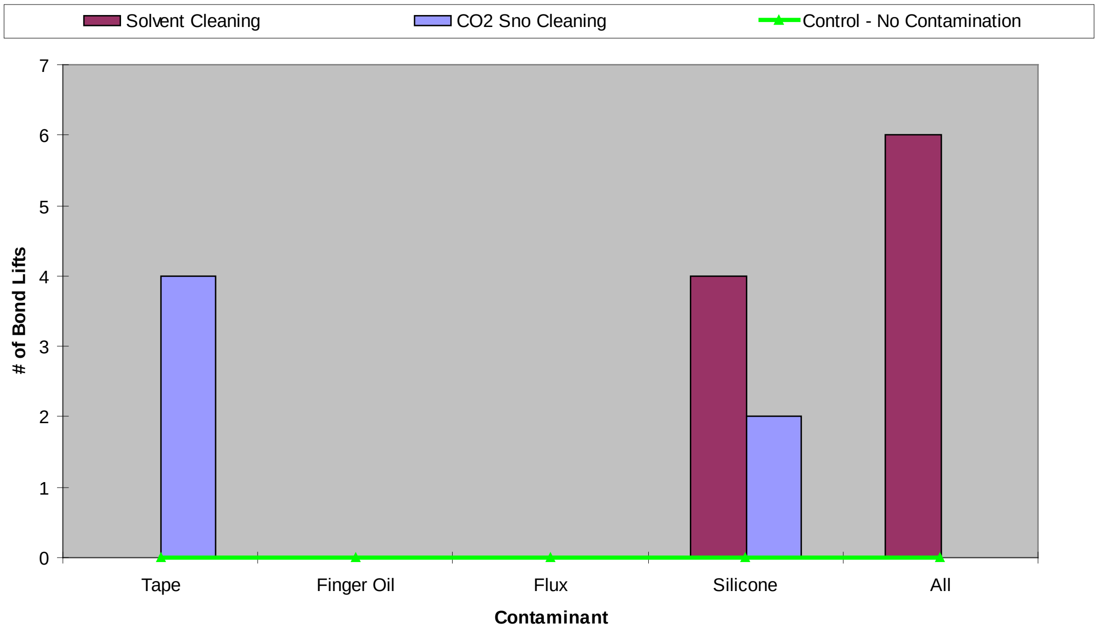

Fig. 7. Bond lift comparisons

As shown in Figure 7, the CO_2 process showed a lower aggregate number of bond lifts as compared to the solvent/plasma cleaning group. CO_2 cleaning performed equal to or better than solvent/plasma cleaning process for finger oils, flux, silicone and for all contaminant mix coupons. Although the contamination data suggests that solvent/plasma cleaning produced better results for tape residue, this was due to contributions from edge contamination residues remaining following selective spray treatment with CO_2. This phenomenon is explained in the discussion above under the heading Surface Contamination Challenge. Surface contamination comparisons are provided in the attached technical report.

Average Bond Pull Strength (g)

Control Group: 58 g

Shown in the Figure 8, all ribbon bond pull strength test measurements for both solvent/plasma and CO_2 cleaning for each type of contaminant were a magnitude higher than the 6.8 g minimum pull strength per MIL-STD-883, Method 2011.7 (3).

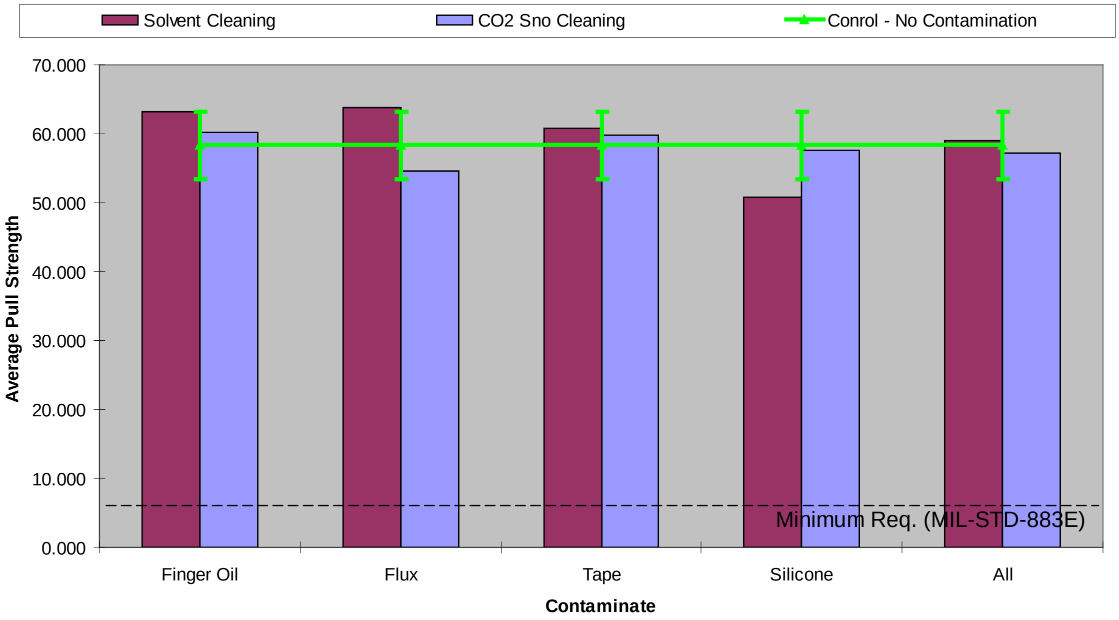

Fig. 8.Pull strength comparisons

Bond Pull, Defects per Million (DPM)

Control Group: 233 DPM

The Solvent/Plasma treatment group showed a higher aggregate DPM compared to CO2 cleaning.

Solvent/Plasma: 117664.7 DPM
CO2 Cleaning: 17051.8 DPM

Shown in Figure 9, the data shows that CO2 Cleaning represents only 2% of the DPM as compared to Solvent/Plasma cleaning which represents 98% of the DPM.

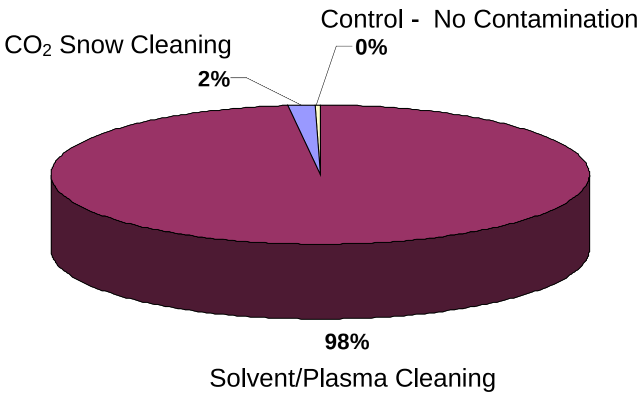

Fig. 9. DPM comparisons

Bond Pull, CpK

Shown in Figure 10, the CO2 cleaned coupons showed a tighter distribution within the established control limits as compared to Solvent/Plasma cleaning. The CpK data indicates that the CO2 cleaning is more effective at removing silicone contamination than Solvent/Plasma cleaning, with the Solvent/Plasma CpK data falling below the Lower Safety Limit (LSL).

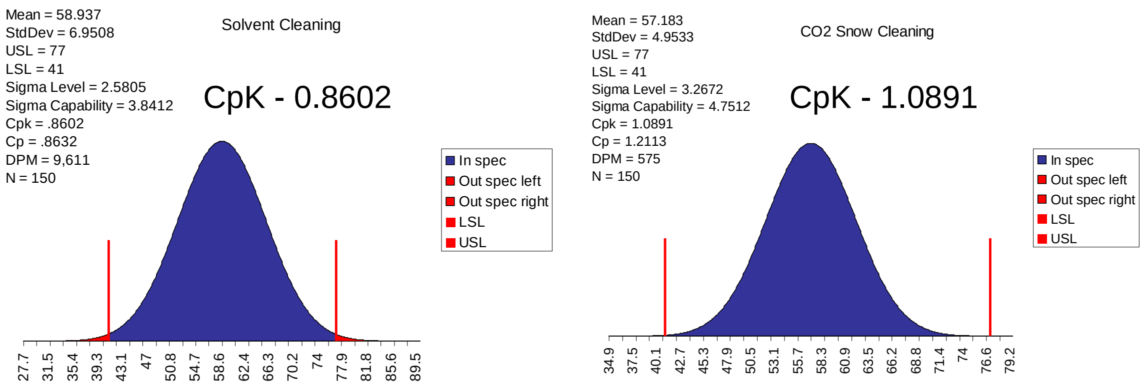

Fig. 10. CpK comparisons

OSEE Data

The data shown in Table 1 indicates that OSEE can be reliably employed to determine the cleaning effectiveness of CO_2 spray cleaning. The OSEE photocurrent increases with surface cleanliness.

Contaminant	Coupon Serial No.	OSEE Initial	OSEE Final	% of Initial Read
Tape	7	92	426	462%
Tape	8	91	548	602%
Finger Oil	21	145	177	122%
Finger Oil	22	30	57	190%
Flux	36	63	472	754%
Flux	37	110	246	225%
Silicone (RTV)	55	455	725	159%
Silicone (RTV)	56	360	743	206%
Control	61	388	282	73%
Control	62	511	315	62%
All	94	178	691	389%
All	96	177	726	411%

Table 1. OSEE measurements for CO_2 cleaned coupons

Conclusion

The test results of this evaluation demonstrate that CO_2 spray cleaning is as good as or better than a Solvent/Plasma cleaning process. CO_2 cleaning was determined to be better for some types of contaminants (i.e.,all contaminant mix), which is more representative of surface contamination conditions for a typical wire bonding process. The new CO_2 cleaning process demonstrated a lower defect-per-million (DPM) level and an improved CpK (CpK>1) over the previous process.

Following a statistically significant evaluation, the previous surface treatment process was replaced with a new CO_2 cleaning system and process. The CO_2 snow spray process was also augmented with a new CO_2 plasma technology (BlueFire$^{\mathrm{TM}}$) which provides additional surface cleaning energy as well as electrostatic control benefits.

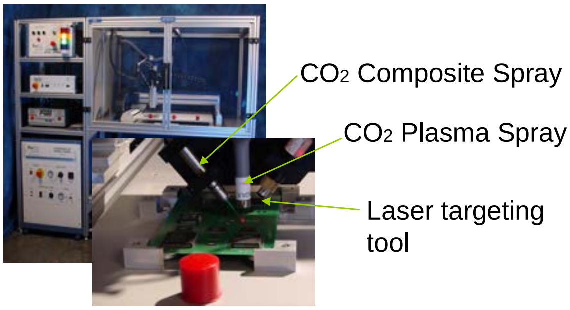

Fig. 11. SnoBot robotic cleaning system (with BlueFire)

The new selective CO_2 plasma-snow surface treatment system (SnoBot$^{\mathrm{TM}}$), shown in Figure 11, features a programmable robotic cleaning system with a Cartesian robot, hybrid spray applicator and air-ionized ESD dissipative minienvironment.

The CO_2 cleaning process does not produce waste by-products such as spent cleaning solvents, wipers and associated cleaning residues. The automated cleaning process provides a robust surface treatment process which much less susceptible to surface contamination variations and a more efficient selective cleaning operation requiring much less labor. Moreover, the CO_2 cleaning process is a lean and clean operation, producing a dry and clean surface in a single-step without waste by-products. Finally, the OSEE test results demonstrated that this on-line non-contact surface cleanliness evaluation technique can be implemented side-by-side with the CO_2 snow-plasma spray cleaning process.

Applicable Industries

Aerospace/Defense
Medical
Electro-Optical
Microelectronic
Hard Disk Drive

Applicable CO_2 Technology

CO_2 Processer Unit (CPU™)
Plasma Blast™ Technology
CO_2 Composite Spray™ Technology

Related Assembly Products/Processes

Ultrasonic Wire Bonder
Wire Bond Pull Tester
Build-Clean Protocol
Selective Cleaning
Rework Operation

Select Industry Testing Standards

EIA/JEDEC, Wire Bond Shear Test Method, EIA/JESD22-B116
MIL-STD-883E, Method 2023.5, Non-destructive Bond Pull

References

1. “Bare Die: Die Attach and Wire Bonding, Guidance for Setting up Assembly Processes”, Application Note AN-1061, R. Clark, International Rectifier
2. Cleaning Project Technical Report, October 22, 2004, Customer/Application Confidential
3. MIL-STD-883E, Method 2011.7, Non-destructive Bond Pull
4. “Bond Surface Evaluation by OSEE Instrument Titan IV Payload Fairing”, R.P. Date, Manufacturing Engineering Department, Design Engineering Subdivision, March 12, 1991, The Aerospace Corporation
5. “Optically Stimulated Electron Emission (OSEE): A Non-Invasive Technique for Contamination Detection”, G. Epstein et al, Manufacturing Engineering Department, The Aerospace Corporation

Keywords

Aerospace
Printed Circuit Board
Flip Chip
Bond Pad
Ultrasonic Wire Bonding
Rework
Surface Treatment

Another clean idea…

think clean.

U.S. Sales Office:
26074 Ave. Hall Unit 6
Sanata Clarita, California 91355
(661) 430-6767

Asia Sales Office:
No. 2 Pioneer Sector 1
Singapore, 628414

www.cleanlogix.com