DECAPSULATION OF PLASTIC ENCAPSULATED SEMICONDUCTOR DEVICES

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1 INTRODUCTION

1.1 SCOPE

The specification describes and specifies the appropriate methods, procedures, equipment and sequences for optimal decapsulation of plastic encapsulated semiconductor devices. In relevant sections of this specification, methods for the decapsulation process and device preparation (before, during and after decapsulation) are described together with associated problems and precautions. These will differ depending on the characteristics of the encapsulant and the protective casing to be removed.

1.2 PURPOSE

This specification is applicable to all plastic encapsulated semiconductor devices, which have to be opened for further investigations and assessment during Construction Analysis (CA), Destructive Physical Analysis (DPA) and Failure Analysis (FA) for evaluation or procurement of such devices.

2 TERMS, DEFINITIONS, ABBREVIATIONS, SYMBOLS AND UNITS

The terms, definitions, abbreviations, symbols and units specified in ESCC Basic Specification No. 21300 shall apply. Furthermore following terms and definitions shall apply.

2.1 DEFINITIONS

2.1.1 Sample

The sample is the quantity of individual Plastic Encapsulated Semiconductor Devices taken at random from each production lot for DPA or CA, or it is the special device, which has to be investigated for FA.

2.1.2 Specimen

The sample device, which has to be opened.

2.1.3 Decapsulation

Decapsulation is the process of removal of any protective casing from the semiconductor die and/or any other chip used in a Plastic Encapsulated Device including the bond wires.

2.1.4 PED

Plastic Encapsulated Device.

2.2 ABBREVIATIONS

2.2.1 Abbreviations for Package Outlines

Abbreviations for package outlines mentioned in this specification are defined in Annex II.

3 DIFFERENT PROCEDURES FOR DECAPSULATION

This paragraph gives an overview of all applicable methods and procedures for the decapsulation of PEDs.

3.1 GENERAL PROCEDURE FOR DECAPSULATION

Chart I gives an overview for the complete procedure. Decapsulation requires some initial preparatory steps such as specimen preparation, x-ray investigation, pre-bake, milling or masking. The preparatory steps are described in Section 4. After preparation, the decapsulation itself can be carried out and must be appropriate for the dimensions, form and material of the device to be opened.

Four different methods for decapsulation are described in paragraphs 5.1 to 5.4. The methods are:

- Manual wet etching,
- Complete wet etching,
- Automated wet etching
- Plasma etching.

Finally, after the etching process has been completed, post-preparation of the sample(s) must be carried out before making further investigations. The post-processing consists of cleaning and drying and shall avoid any corrosion of the individual metal parts of the PED.

A guideline for the selection of the most applicable method, the acid and the temperature is given in Figure II. Further, Section 6 gives important and useful precautions for safety, handling and processing.

3.2 STATUS OF DECAPSULATION

The status of possible decapsulation is shown in Figure II. The amount of decapsulation shall be chosen to be appropriate for the investigations performed after decapsulation as shown in Table I.

Three different states of decapsulation A, B and C are defined according to the dimensions of the opened area with respect to the die(s), bond wires and lead frame.

Before beginning with a decapsulation procedure, it must be clearly defined which opened area is to be achieved:

- Status A: This status defines that the removal of moulding material from the surface of the die (or dies) should expose the die bond pad, the loop in the bond wire, and at least 75% of the bond wire length.
- Status B: This status defines that the removal of moulding material from the surface of the die (or dies) should expose the die bond pad, the lead frame bond pad, the loop in the bond wire, and 100% of the bond wire length.
- Status C: This status defines that the moulding material is completely removed from the specimen (the lead frame must be stabilised).

CHART I – DECAPSULATION PROCEDURES

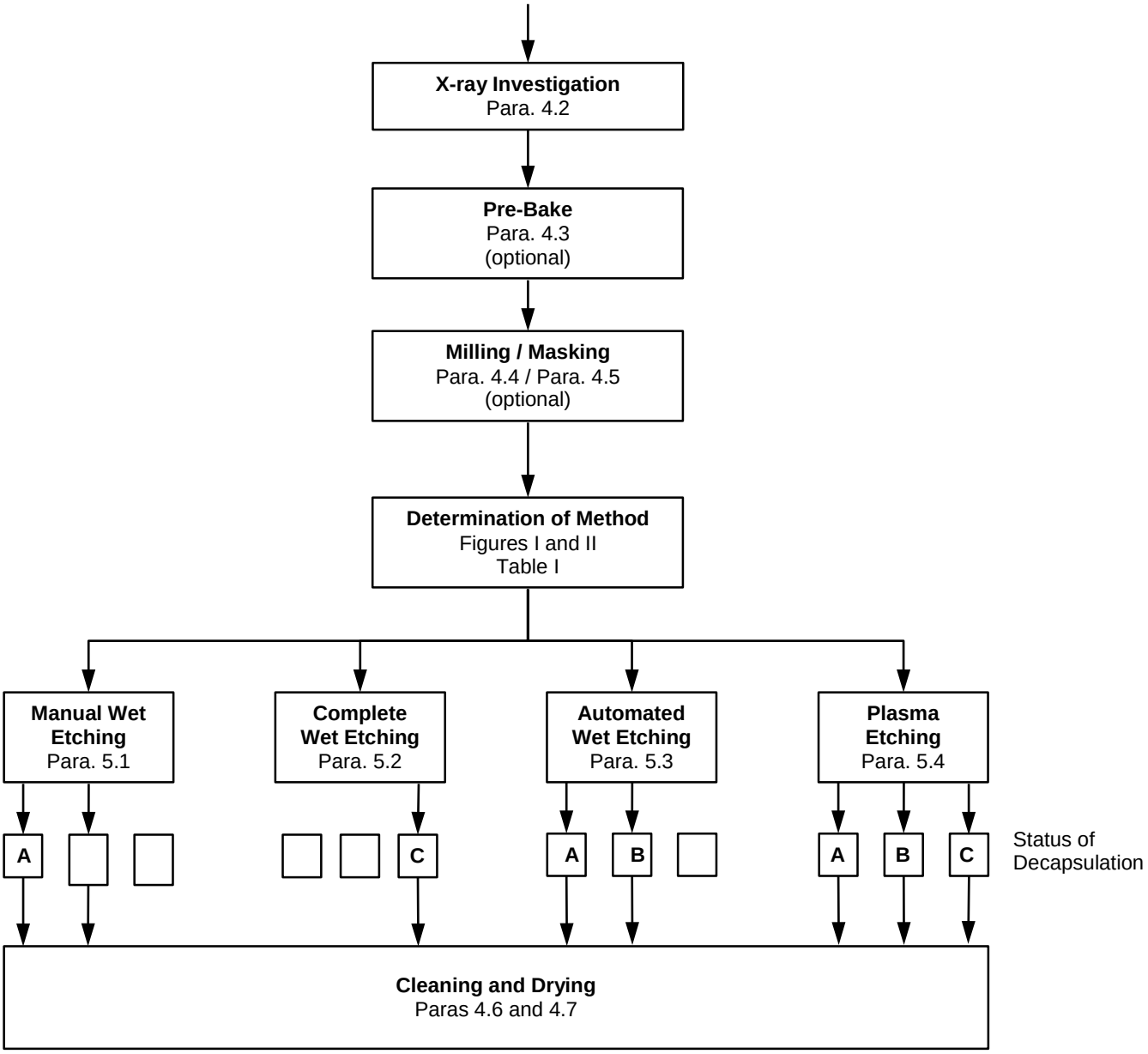
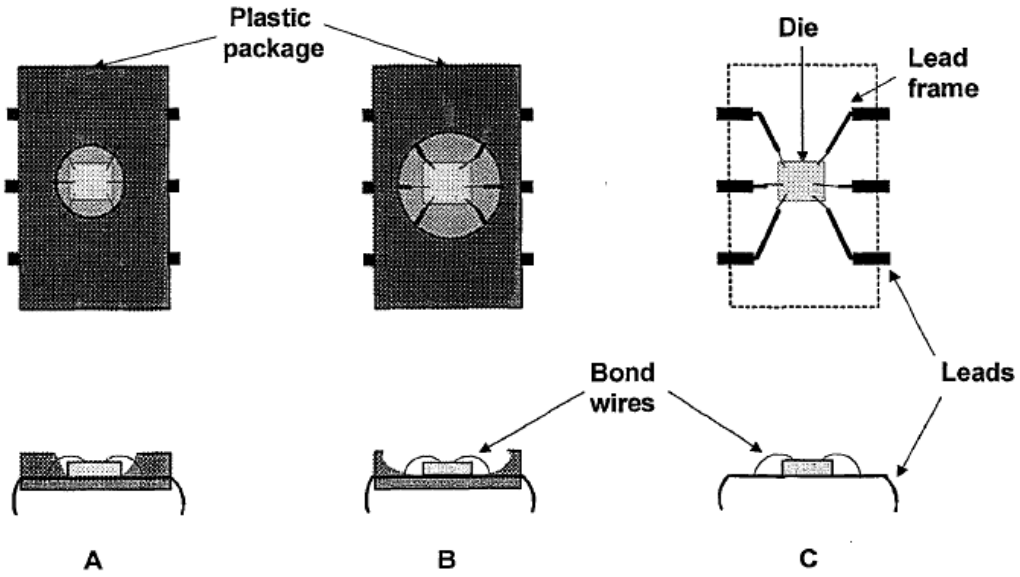


FIGURE I – STATUS OF DECAPSULATION

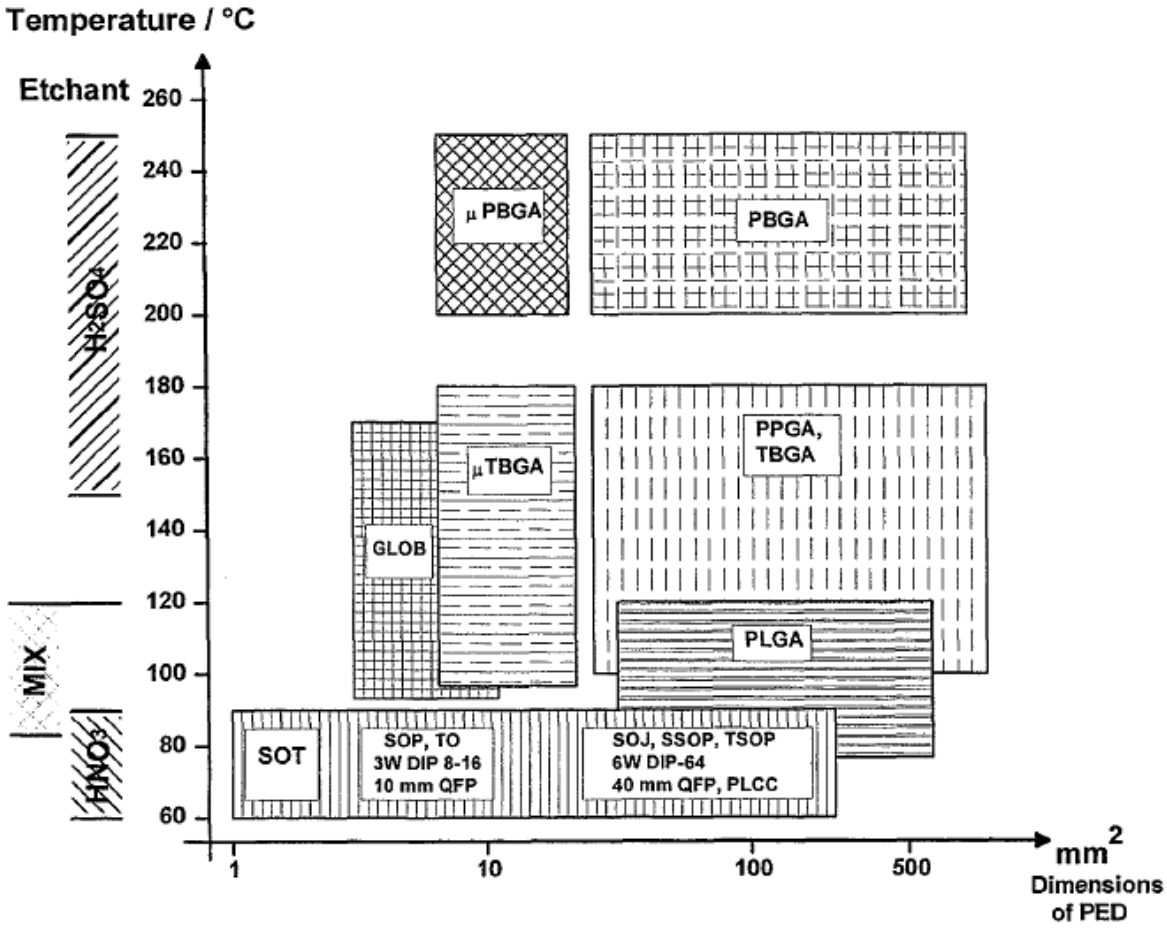


Status of Decapsulation (example for 6-DIL Plastic DIP)

TABLE I – POSSIBLE INVESTIGATIONS AFTER DECAPSULATION

Status of Decapsulation		Possible Investigations After Decapsulation	Remarks
A	Removal of moulding material from the surface of the die (or dies), exposing • the die bond pad, • the loop in the bond wire, and • at least 75% of the bond wire length.	• Inspection of the die surface • Inspection of the bond wires (partly) • Inspection of the die attach • Electrical test • Bond wire pull test • Die-shear test	 if applicable
B	Removal of moulding material from the surface of the die (or dies), exposing • the die bond pad, • the post bond pad, • the loop in the bond wire, and • 100% of the bond wire length.	• Inspection of the die surface • Inspection of the whole bond wires • Inspection of the die attach • Inspection of the lead frame/paddle • Electrical test • Bond wire pull test • Die-shear test	
C	Complete removal of all moulding material (The lead frame must be stabilised)	• Inspection of the die surface • Inspection of the whole bond wires • Inspection of the die attach • Inspection of the lead frame/paddle • Electrical test • Bond wire pull test • Die-shear test	 if applicable if applicable if applicable if applicable

FIGURE II – GUIDELINE FOR THE CHOICE OF THE ETCHANT AND THE TEMPERATURE



NOTES:

MIX: This can be a 2:1 or 9:1 mixture of nitric acid (HNO_3) and sulphuric acid (H_2SO_4).

For abbreviations see Annex II.

4 SPECIMEN PREPARATION

4.1 INTRODUCTION

Decapsulation generally involves five discrete steps: X-ray investigations as a preliminary step, a baking process to eliminate water, milling to create a small indentation or masking, a chemical etch process and finally cleaning and drying.

4.2 X-RAY INVESTIGATION

X-ray analysis should be performed before decapsulation to determine the shape, placement and size of the die(s) and to determine the height of the bond-wires. This information will assist in choosing the correct mask or gaskets and the depth of the trench to be milled in the package surface.

The area that is to be milled must be clearly identified.

4.3 PRE-BAKE

It is recommended that PEDs be baked before wet etching to eliminate any moisture in the moulding material. The pre-bake reduces the possibility of corrosion of the lead frame and the bond-pads during decapsulation. If temperature and duration for pre-bake is defined in the detail specification for the part then this temperature and duration shall be used. If not, a temperature of 125°C for at least 16 hours shall be used.

4.4 MILLING

This step is recommended and often useful for Manual Wet Etching and Plasma Etching. Milling should ensure that the die surface is exposed before the lead frame, and it also reduces the time required for etching. A milling machine with sufficient accuracy for the size of the package being decapsulated and capable of producing flat milled surfaces shall be used.

The procedure is as follows:

1. Using x-ray data, calculate the depth of the trench to be milled.
2. Install the specimen into the fixture of a milling machine.
3. Start milling, moving the mill tip down to the calculated depth. Mill the trench slightly longer and wider than the die area which shall be opened. The bottom of the trench should be parallel to the surface of the die.

To ensure that the bond wires remain intact during milling, it is recommended that approximately 0.2mm of moulding compound remain covering them. The accuracy of the milling machine should be sufficient to guarantee that no damage to the bond wires can occur during milling.

4.5 MASKING

After identification of the internal structure with x-ray investigation, as an alternative to milling, a mask can be used for shielding the specific areas not to be etched. The material for the mask can be aluminium foil, adhesive tape or any other acid and high temperature resistant material. The mask must have good contact to the package surface.

4.6 CLEANING

After decapsulation, the specimen should be cleaned. The cleaning step to be applied is described individually for each of the decapsulation methods described in this specification. The use of an ultrasonic cleaning system is only acceptable, if no other method can sufficiently clean the die(s) for further inspection.

4.7 DRYING

To avoid corrosion of the specimen it should be blow-dried using dry nitrogen as a last step before further investigation and/or storage.

5 DECAPSULATION

The purpose of this step is to open the plastic package so that:

(a) The whole die is free and clean of any encapsulant.
(b) The device is still electrically functional.
(c) Visual inspection of the die can be made.
(d) The bond wires and their bonds are not degraded.
(e) Valid bond pull tests can be performed.
(f) Valid die shear testing is possible.
(g) Damage to the metallisation and glassivation of the die and the semiconductor material is minimised.

In the following sections different methods for the decapsulation of PEDs will be defined. At the beginning of each section a short recommendation of the applicability of the method is given.

5.1 MANUAL WET ETCHING

Manual Wet Etching is particularly useful if a new part type is to be decapsulated and the progress of the etching procedure is to be followed step by step in order to guarantee good control over the decapsulation process. This method is recommended for individual part types and dimensions, where no special mask and/or apparatus is available and where small quantities of PEDs are to be opened.

The process is performed manually, so that the die (or dies) and the bond-wires are exposed to the required extent. The method can be used to open plastic packages until either status A or status B of decapsulation is achieved (see Figure I).

The following chemicals are required:

- HNO_3 : (fuming nitric acid), 100% or red fuming nitric acid > 90%
- H_2SO_4 : (sulphuric acid), 100%
- Acetone with low water content
- Deionized water
- A liquid cleaner (e.g. photoresist stripper or acetone)
- Dry nitrogen gas (gun)

The following equipment is required:

- A milling machine
- A hotplate covered with thin aluminium foil
- Glass beakers
- An eyedropper
- Tweezers
- A microscope
- An ultrasonic cleaning system (see Para. 6.2)

Equipment set-up:

(a) Depending on the chemicals used set the hotplate to the required temperature (see Figure II).
(b) Use a metal form plate to place the specimen in good contact to the heat plate (see Figure III).
(c) Prepare a beaker of liquid cleaner. If ultrasonic cleaning is to be used then place the beaker into the ultrasonic cleaning system (see Para. 6.2).

Procedure:

(a) Mill a hole in the upper surface of the package as described in Para. 4.4.
(b) For devices with more than one die, each die should be decapsulated separately.
(c) Place a small amount (approximately 40ml) of acid in a beaker (if 9:1 mixed etchant is to be used then 40ml HNO_3 and 4ml of H_2SO_4).
(d) Place the specimen on the hot plate onto the metal form plate and allow it to heat up to the required temperature.
(e) With an eyedropper, place 1-2 drops of fuming nitric acid or 9:1 mixed etchant on the package surface and allow time for the reaction to take place (the surface should begin to bubble and turn black).
(f) Remove the specimen from the hot plate with tweezers and rinse with acetone into an acetone waste beaker.
(g) Repeat steps c) to f) until the die is sufficiently exposed.
(h) Clean the decapsulated device using the beaker of liquid cleaner (with the assistance of ultrasonic vibration where required) until it is sufficiently clean when optically inspected under low power magnification (see Para. 6.3).
(i) Remove the specimen from the liquid cleaner with tweezers and remove excess cleaner by rinsing with deionized water. Finally rinse the device with acetone and gently blow dry with dry nitrogen.

5.2 COMPLETE WET ETCHING

Complete Wet Etching is recommended if, in addition to the die(s) and the bond wires also the lead frame is to be inspected. The advantage of this method is that the whole specimen is immersed in the etchant. For very small packages, e.g. SOT package types, this is the only applicable wet chemical method of etching because Manual or Automated Wet Etching is not selective enough to only expose the die.

For this method, measures have to be taken to ensure that the individual parts of the lead frame remain together after decapsulation, e.g. by soldering the leads together on a baseplate.

This section describes a method for complete decapsulation of the specimen. The process is carried out manually and the moulding material is completely removed from the device, so that status C of decapsulation is achieved (see Figure I).

The following chemicals are required:

- HNO_3 : (fuming nitric acid), 100% or red fuming nitric acid > 90%
- H_2SO_4 : (sulphuric acid), 100%
- Acetone with low water content
- Deionized water
- A liquid cleaner (e.g. photoresist stripper or acetone)
- Dry nitrogen gas (gun)

The following equipment is required:

- A hotplate covered with thin aluminium foil and a suitable protective metal plate
- Glass beakers
- Tweezers
- A microscope
- An ultrasonic cleaning system (see Para. 6.2)
- A Teflon device holder

Equipment set-up:

(a) Depending on the chemicals used set the hotplate to the required temperature (see Figure II).
(b) Place a beaker of etchant into the opened area of the protective metal plate of the hotplate.
(c) Prepare a beaker of liquid cleaner. If ultrasonic cleaning is to be used then place the beaker into the ultrasonic cleaning system (see Para. 6.2).

Procedure:

(a) Check the position of the die(s) and the lead frame with x-ray inspection.
(b) Take measures to ensure that the individual parts of the device stay together after total decapsulation (e.g. by soldering all the leads together on a baseplate).
(c) Place approximately 100ml of acid in the beaker (for 9:1 mixed etchant 100ml HNO_3 and 10ml of H_2SO_4 should be used).
(d) Allow the etchant to heat up to the specified temperature.
(e) Place the specimen into the Teflon device holder and immerse it in the liquid etchant.
(f) After complete decapsulation of the device the Teflon device holder should be removed from the etchant with tweezers.
(g) Rinse with acetone into an acetone waste beaker.
(h) Clean the decapsulated device using the beaker of liquid cleaner (with the assistance of ultrasonic vibration where required) until it is sufficiently clean when optically inspected under low power magnification (see Para. 6.3).
(i) Remove the specimen from the liquid cleaner with tweezers and remove excess cleaner by rinsing with deionized water. Finally rinse the device with acetone and gently blow dry with dry nitrogen.

5.3 AUTOMATED WET ETCHING

Generally, Automated Wet Etching shall be used when a large quantity of devices should be decapsulated and when this method will yield better results than Manual Wet Etching. An advantage of this technique is that the chemical reaction takes place in an oxygen free chamber so that possible corrosion is suppressed.

This section describes a method for decapsulation which makes use of specific equipment designed and manufactured for decapsulation of PEDs. Equipment of this kind is commercially available and makes use of jet etching in a partial vacuum.

The die or dies and the bond wires of the specimen can be selectively exposed. The method can open plastic packages until either status A or status B of decapsulation is achieved (see Figure I).

The following chemicals are required:

- HNO_3 : (fuming nitric acid), 100% or red fuming nitric acid > 90%
- H_2SO_4 : (sulphuric acid), 100%
- Acetone with low water content
- Deionized water
- A liquid cleaner (e.g. photoresist stripper or acetone)
- Dry nitrogen gas (gun)

The following equipment is required:

- Any commercial or self-made apparatus.
- A mask (flexible, acid and temperature resistant material)
- Tweezers
- A microscope
- An ultrasonic cleaning system (see Para. 6.2)

Equipment set-up: (see Figure IV, principle set-up of the apparatus)

(a) Set the hotplate (of the apparatus) to the required temperature (see Figure II).
(b) Place the specimen into the apparatus with a mask appropriate for the specimen to be decapsulated.
(c) Prepare a beaker of liquid cleaner. If ultrasonic cleaning is to be used then place the beaker into the ultrasonic cleaning system (see Para. 6.2).

Procedure:

(a) Check the position of the die(s) and the lead frame using x-ray investigation.
(b) Choose a suitable mask.
(c) Place the specimen into the apparatus with the mask.
(d) Check, that sufficient fresh etchant (HNO_3, H_2SO_4 or 9:1 mixture) and acetone are available.
(e) Heat the specimen to the required temperature.
(f) Start the Program (according to the operating instructions for the equipment). The specimen will then be exposed to a number of cycles of etching and cleaning using acetone. If the decapsulation is then not completed, manual or automatic etching cycles should be carried out until the required status is achieved.
(g) Clean the decapsulated device using the beaker of liquid cleaner (with the assistance of ultrasonic vibration where required) until it is sufficiently clean when optically inspected under low power magnification (see Para. 6.3).
(h) Remove the specimen from the liquid cleaner with tweezers and remove excess cleaner by rinsing with deionized water. Finally rinse the device with acetone and gently blow dry with dry nitrogen.

5.4 PLASMA ETCHING

Plasma etching has very high selectivity and the use of the technique minimises etching of the die and the lead frame. The safety and contamination problems associated with wet chemical etching are avoided. Plasma treatment is a gentle process compared to wet etching and makes it possible to expose the bonds at both ends of the wires. The disadvantage of plasma etching is that significantly more time is required to carry out the decapsulation procedure. The process duration for plasma etching varies typically between 5 and 15 hours depending upon the type of the device and the trench depth.

This section describes a method of Plasma Etching, which can be used to selectively expose, the die (or dies) and the bond wires. This method can be used to open the plastic package until either status A or status B of decapsulation is achieved (see Figure I).

Chemicals and equipment:

- A non-reactive ion etching mode plasma should be used. In appropriate equipment, the moulding compound is etched and removed from the device and several devices can be treated simultaneously. In some types of equipment, the filler material (e.g. quartz powder) is automatically blown from the surface with brief blasts of compressed air at time intervals of a few minutes.
- Decapsulation is normally performed at approximately 0.5 - 1 mbar pressure of the gas mixture O_2:CF_4 (80:20).
- No special frequency can be specified. The standard frequency of most apparatus is 2.4GHz. (Some types of components are sensitive to damaged caused by low frequency plasma).

Procedure:
(a) Mill a trench as described above in Section 4.4.
(b) If necessary, cover the package with an aluminium foil mask so that only the area to be etched is exposed to the plasma.
(c) Adjust and secure the specimens under the blow nozzles. The leads should be short-circuited to avoid charging of the device.
(d) Start the etching process.
(e) Residues of solid materials (quartz powder, pigments etc.) must be periodically removed from the surface of the specimen(s) during the process.

Caution:
Oxygen/Freon plasma (frequently used for decapsulation) does not affect AI and Au, but can attack other metals and glassivation (particularly Si_3N_4).

Overheating of the devices during plasma etching should be avoided e.g. by periodically pausing in the etching process in order to allow the specimen to cool.

6 PRECAUTIONS

6.1 PRECAUTIONS FOR SAFETY

All procedures described should be performed in a laminar flow hood with an acid sink. The laminar flow hood should be used only for decapsulation procedures.

The person(s) carrying out the decapsulation must wear acid protection clothing (acid resistant apron, mask or goggles and gloves) before handling the acids. Furthermore, s/he should be aware of all the dangers and possible reactions of the acids being used!

6.2 PRECAUTIONS FOR HANDLING

As protection against ESD, conductive shoes and/or heel straps should be used. A grounded metal plate should be placed under the area where the specimens are being handled.

The frequency of the ultrasonic bath should not be close to the resonance frequency of the bond wires. If the use of an ultrasonic bath is not necessary for further investigations it should be avoided.

Be aware that the devices shall not be over-etched after exposing the lead frame and paddle. Over-etching of the bonds or the die(s) can cause under-cut so that the die and bond wires detach from the lead frame or paddle!

The etchants HNO_3, H_2SO_4, and mixed etchants should be applied in the correct range of temperature, otherwise the effectiveness of the etchant may be impaired. HNO_3 should not be used above 90°C and if an acid mixture is too hot the HNO_3 will vaporise quickly.

6.3 RECOMMENDATIONS

If the device has been severely electrically overstressed (associated with heat) it may be difficult to remove carbonised moulding compound (the use of oxygen plasma is an additional procedure, which can be used to remove carbonised moulding compound from the die surface).

The use of a 9:1 or 2:1 (HNO_3 : H_2SO_4) mixture is recommended for parts with copper bonds or copper lead frames.

For certain encapsulant materials, e.g. urethane, epoxy, PVC or ABS the etchant H_2SO_4 should be used at 240°C.

FIGURE III – PRINCIPLE SET-UP FOR MANUAL WET-ETCHING

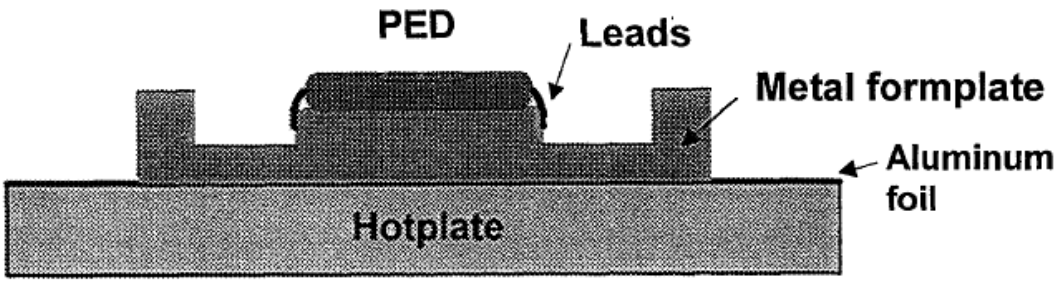
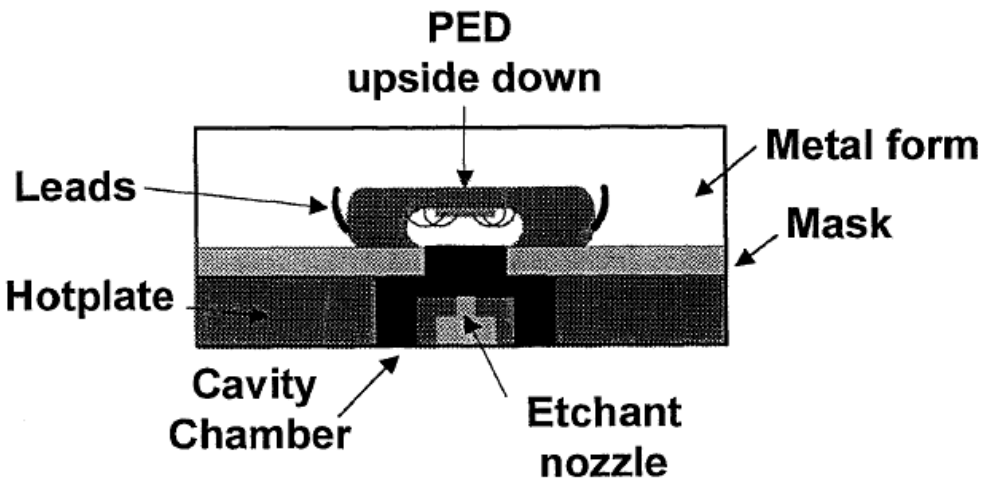


FIGURE IV– PRINCIPLE SET-UP FOR AUTOMATED WET-ETCHING



ANNEX I – APPLICABLE DECAPSULATION METHODS FOR PLASTIC ENCAPSULATED DEVICES

PACKAGE OUTLINES	METHODS			
	Manual Wet Etching (Para. 5.1)	Complete Wet Etching (Para. 5.2)	Automated Wet Etching (Para. 5.3)	Plasma Etching (Para. 5.4)
SOT		X		X
DIP	X	X	X	X
SIP	X	X	X	X
ZIP	X	X	X	X
SVP	X	X	X	X
SOJ/SOL/SOP	X	X	X	X
SSOP / SQFP	X	X	X	X
TSOP / TQFP	X	X	X	X
SON	X		X	X
QFP			X	X
LCC / QFN	X		X	X
PCLP	X		X	X
QFJ	X	X	X	X
(µ)TBGA / PPGA			X	X
PLGA	X	X	X	X
PPGA / (µ)PBGA			X	X
SMD	X	X	X	X
SIMM / DIMM	X	X	X	X
GLOB	X	X	X	X

NOTE:
For abbreviations see Annex II.

ANNEX II – ABBREVIATIONS

DIMM	Dual In-line Memory Module
DIP	Dual In-line Package
GLOB	Glob Top
LCC	Leadless Chip Carrier
PBGA	Plastic Ball Grid Array
PCLP	Printed Circuit-board Leadless Package
PLCC	Plastic Leaded Chip Carrier
PLGA	Plastic Leaded Grid Array
PPGA	Plastic Pin Grid Array
QFJ	Quad Flat J-Leaded Package
QFN	Quad Flat Non-Leaded Package
QFP	Quad Flat Package
SIMM	Single In-line Memory Module
SIP	Single In-line Package
SMD	Surface Mounted Device
SOJ	Small Outline J-Leaded
SOL	Small Outline Package L-Leaded Package
SON	Small Outline Non-leaded Package
SOP	Small Outline Package
SOT	Small Outline Transistor
SQFP	Small Quad Flat Package
SSOP	Shrink to Small Outline Package
SVP	Surface Vertical Package
TBGA	Thin Ball Grid Array
TQFP	Thin Quad Flat Package
TSOP	Thin Small Outline Package
ZIP	Zig-Zag In-line Package
µPBGA	Small Plastic Ball Grid Array
µTBGA	Small Thin Ball Grid Array