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LOW PRESSURE PLASMA PROCESSING IN MICROELECTRONICS

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Key words: electronics, microelectronics, plasma processing, low pressure plasma, low pressures, surface treating, surface etching, surface coatings, IC, integrated circuits, plasma drilling, PCB, printed circuits boards, wafer fabrication, decoating.

Abstract: Low pressure plasmas are widely used for treating, etching and coating surfaces of different materials. This technique is indispensable for manufacturing of very large scale integrated circuits used by the microelectronics and electronics industry. In this paper new applications of low pressure plasma processing are presented:

Dry cleaning of wafer boats coated by LPCVD - Si and Si_3N_4 through plasma etching leads to a dramatic reduction of boat replacement. Ashing of photoresist in IC fabrication using modern microwave batch systems is much more economical than the classic single-wafer process. Cleaning of substrates on which ICs are mounted increases strongly the pull strength of wire bonds and improves the adhesion of mouldings used for IC encapsulation. Plasma drilling of microvias into thin flexible PCBs pushes the dimensions of PCB structures beyond the limits set by the conventional, mechanical drill process.

Uporaba nizkotlačnih plazemskih procesov v mikroelektroniki

Ključne besede: elektronika, mikroelektronika, procesiranje plazemsko, plazma nizkotlačna, pritiski nizki, obdelava površinska, jedkanje površinsko, prevleke površinske, IC vezja integrirana, vrtanje plazemsko, PCB plošče vezja tiskanega, proizvodnja rezin, odstranjevanje prevlek.

Povzetek: Procese, ki potekajo v nizkotlačni plazmi množično uporabljamo za obdelavo, jedkanje in prekrivanje površin različnih materialov. Ta tehnika je nepogrešljiva pri proizvodnji integriranih vezij zelo visoke stopnje integracije, ki jih danes uporabljata mikroelektronska in elektronska industrija. V tem prispevku pa predstavljamo nekatere nove možnosti uporabe procesov v nizkotlačni plazmi.

Suho plazemsko čiščenje ladjic za rezine, ki so prekrite z debelim nanosom LPCVD silicijevega nitrida, omogoča dramatično znižanje števila zamenjav ladjic zaradi poškodb. Odstranjevanje fotorezista v mikrovalovnem šaržnem reaktorju pri proizvodnji integriranih vezij je bolj ekonomično kot klasično čiščenje rezine po rezino. Čiščenje substratov, na katere so pritrjena integrirana vezja v čip obliki v veliki meri poveča trdnost in zanesljivost žičnih povezav med čipom in substratom - ohišjem ter poveča adhezijo materialov, ki jih uporabljamo za zalivanje, oz. zapiranje integriranih vezij. Plazemsko vrtanje mikrolukenj v tanke upogljive PCB substrate omogoča zmanjševanje njihovih dimenzij daleč izpod meja, ki jih narekuje konvencionalno mehansko vrtanje lukenj.

1. Introduction

Low pressure plasmas are known and investigated since the mid of 20s. Many promising features have been found since that time and the new technology entered industrial manufacturing nearly 30 years ago. The large variety of surface modifications which can be obtained by low pressure plasmas as well as environmental and economical aspects are reasons for the further growing interest in this technique.

Excellent results obtained and low running cost due to low consumption of energy and process materials are the most attractive features of plasma processing. The plasma process utilizes inexpensive and easy-to-handle gases only. Workpieces are absolutely dry after treatment and high cost for an additional energy-intensive drying process can be saved. Cost for the disposal of waste and the recycling of wet chemicals can be saved as well. The plasma process requires no special safety measures and provides a cleaner and safer workplace. An important characteristic of low pressure plasma is its penetrating power. The gas penetrates into small pores and structures that are difficult or impossible for liquids to access. Thus, micro-structures can be formed and parts with complex shapes can be processed easily. Due to the manifold of technological, environmental and economical advantages low pressure plasma can be said a powerful tool for future applications in microelectronics and electronics industry.

In this paper newly developed plasma processes are presented that are applied in wafer fabrication, assembling technology and PCB manufacturing.

2. Plasma in Microelectronics

Low pressure plasma processing is well-established in the microelectronics industry, the production of integrated circuits of today´s standard wouldn´t be possible without using plasma. In addition, lab scale plasma equipment is used for IC decapsulation in the case of failure. Recently, dry plasma removal of CVD-layers from long quartz boats has been invented and ashing of photoresists using modern microwave batch systems has been developed to a highly economical process in IC fabrication.

2.1 Decoating of Wafer Boats

Quartz boats used as substrate carrier in IC fabrication are coated several times with CVD - Si and Si_3N_4 during wafer processing and have to be cleaned periodically. Dry plasma decoating recently developed is a new alternative to cleaning of the quartz boats using wet chemicals. The dry plasma process has an improved etch selectivity between quartz and CVD layers reducing the attack on quartz. Therefore, plasma decoating results in an extreme increase in boat life time and leads to a dramatic cost reduction on quartz ware. Cost for the consumption and disposal of wet chemicals are saved as well. These facts are the key arguments for dry plasma decoating. High throughput - two boats can be cleaned in approx. 1 hour cycle time - and cleanroom compatibility of plasma equipment are additional properties which make plasma processing continued attractive for the use in IC fabrication.

Fig. 1 shows the plasma equipment with the process chamber opened. The system is capable to hold two 80 cm long quartz boats. A plasma power of 2.4 kW totally is supplied by four microwave generators working at a frequency of 2.45 GHz.

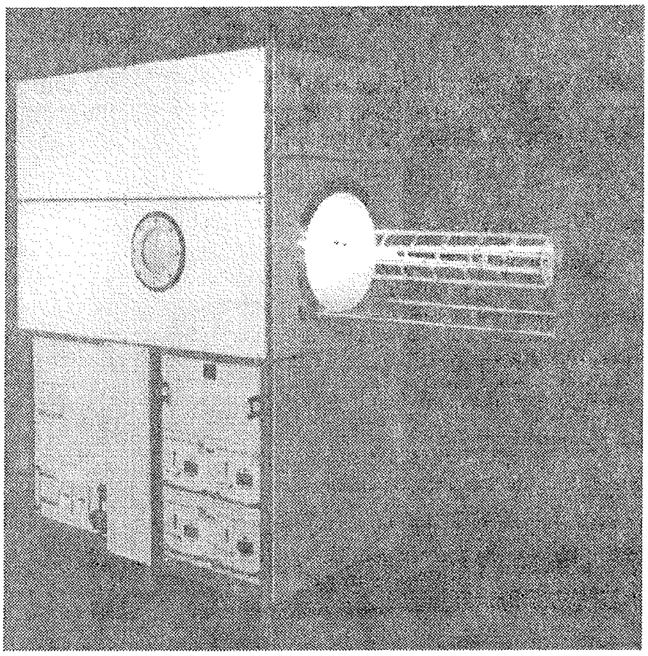

Fig. 1: Plasma equipment for dry removal of CVD layers on long quartz boats.

2.2 Smart Ashing of Photoresist

Photo resist stripping is a regular process during wafer fabrication. The strip process is carried out up to 20 times for the production of a CMOS wafer. Current etch technique is the single-wafer process using RF plasma in competition to wet chemical processes. Through recent developments the single-wafer process is replaced by a batch process in a low pressure plasma applying modern microwave technology. The main difference between the two processes is the time of plasma treatment resulting in a lot of advantages on the side of the newly developed batch process. The most important is the improved yield for batch processing (Tab. 1). Whereas low throughput of 15 - 50 wafers/h is obtained in the case of single-wafer ashing, high throughput of 60 - 120 wafers/h is achieved for microwave batch ashing. Up to 50 wafers can be processed simultaneously in the latter case. Moreover, the plasma batch system developed has 200 mm wafer capability with unmatched productivity and provides low particle and metal contamination owing to special loading mechanism and quartz materials used. Minimum footprint required in cleanroom area and high process yield results in very low cost-of-ownership for the plasma batch system. Fig. 2 shows the plasma processor 300 Autoload whoose specifications are listed in Tab. 2.

Table 1: Capacity of single-wafer process and batch process

	Single-wafer asher	Batch asher
Process time	1 - 3 min.	20 -50 min.
Loading / unloading	0.5 - 2 min. (per wafer)	5 min. (per batch)
Throughput	15 - 50 wafer/h	60-120 wafer/h

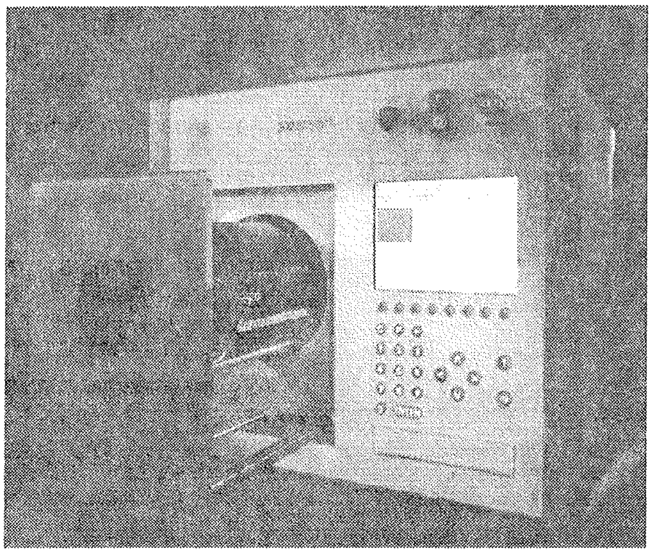

Fig. 2: Plasma system 300 Autoload PC - superior microwave plasma batch system for ashing of photoresist.

Table 2: Plasma system 300 Autoload PC - Specifications

Performance Data	
Maximum batch size	50 wafers per load
Wafer size	all sizes up to 200 mm
Typical cycle time	20-25 min. per batch
Productivity	approx.100 wafers per hour
Uptime	>95%
MTBF	> 500 h
MTTR	<2h
Particle count	< 10 particles (0.12 μ^2 on 6" wafer)
Technical Data	
Quartz process chamber (easy to clean)	ϕ = 245 mm (9.6"), depth 380 mm (15")
Wafer loading	Automated loading mechanism
Microwave plasma generation	Frequency : 2.45 GHz, Power : 0 -1000 Watts
Vacuum gauge	Capacitance manometer, MKS Baratron
Process gas control (up to 4 channels)	Mass Flow Controller, 2 channels standard (2 optional)
Minimum footprint	W/H/D : 705 / 605 / 700 mm 273/4" / 23.8"/ 27 1/2"
Weight	140 kg
System Operation	
System control	Dialog PC 386/33 (optional 486/66), Floppy disk drive, 10" TFT color monitor, RS 232 interface, Optical End Point Detector, IR thermometer
Software package	Manual and automatic operation, graphical display, multiple recipe storage, system check
Option	Automatic cassette loading handler for 150 and 200 mm wafers

In the case of the new batch process there are additional technical benefits in comparison to the single-wafer process. The extended time of plasma treatment effects higher desorption of chemical residues (corrosion inhibition), enables curing of Spin-on-Glass still during the plasma process and provides safe overash as well as backside or double side ash.

The most important benefit of the new system, however, is the use of microwaves of 2.45 GHz for large volume plasma generation. In comparison to RF frequency higher electron density is produced coupled with higher concentration of radicals that are the reactive species in the plasma. Microwave frequency creates not only high plasma density, but also very low self-bias potential on the substrate surface. In Fig. 3 the self-bias voltage is depicted versus the frequency used for plasma exitation. For microwaves of 2.45 GHz the self-bias potential

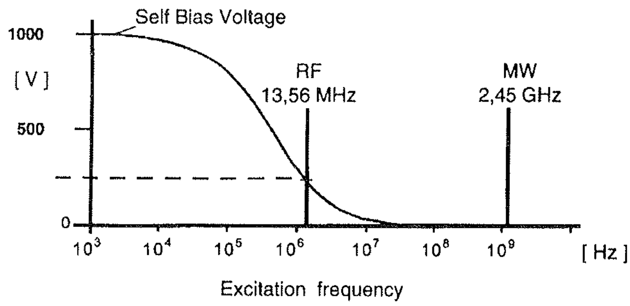

Fig. 3: Self bias potential as a function of the excitation frequency used. Low self bias voltage for microwave frequency.

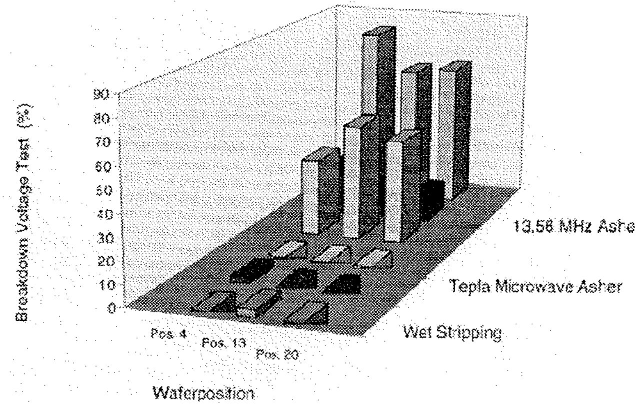

Fig. 4: Gateoxid integrity after resist stripping. Comparison of different etch processes.

is between 5 and 15 Volts typically. Thus, microwave plasmas are damage-free and electronic devices are not destroyed during exposure to plasma. This behaviour has an enormous effect on the gateoxid degradation during photoresist stripping. Up to now extremely low damage level is reported by wafer fabs having long term experience with the new plasma equipment. Gateoxid degradation is investigated by means of break down tests with high voltages applied. Fig. 4 shows the breakdown failure in arbitrary units as a function of different wafer positions in the carrier. Wet chemical etching, plasma ashing in a 13.56 MHz barrel asher and microwave batch ashing are compared. The microwave plasma batch process is superior by far over the competitive plasma process using RF frequency, and it reveals results equal to the wet process. With respect to economical and ecological aspects microwave batch ashing is superior to the wet process as well.

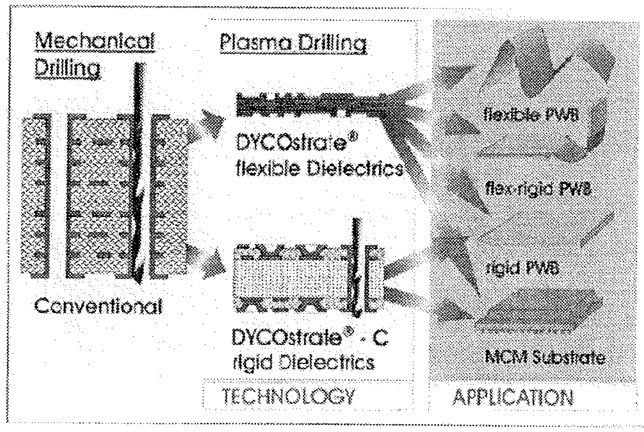

Fig. 5: Basic concept of DYCOstrate® technology.

3. Plasma in PCB Technology

For about 15 years low pressure plasmas are successfully used in PCB manufacturing for drill hole desmear and etch back of multilayer printed circuit boards. Plasma desmearing replaces here the wet etching process using highly aggressive chemicals such as $KMnO_4$. During the last years PCB technology developed rapidly. The dimensions of PCB structures became smaller and smaller, the wire density and the number of layers grew up. Mechanical drilling for formation of interconnections between electric circuit layers is a limiting factor which can be overcome by plasma drilled holes. The new and revolutionary DYCOstrate® technology which has been invented by DYCONEX AG is using a plasma process developed by Technics Plasma GmbH. The continuous miniaturization of PCB structures also results in new assembling techniques for the electronic devices, e.g. the Chip-on-Board technique. Therefore, cleaning of substrates on which ICs are mounted is also presented in this chapter.

3.1 DYCOstrate® - Plasma Drilling

DYCOstrate® technology. The concept of the DYCOstrate® technology which is illustrated in Fig. 5 is simply said the substitution of the mechanical drilling process in glass-reinforced base materials by plasma drilling in thin plasma-etchable dielectrics. The scope of products which can be manufactured using the new DYCOstrate® technology ranges from flexible PWBs to flex-rigid PWBs, rigid PWBs as well as MCM substrates. DYCOstrate® products can be ideally used as substrates for the new direct-assembling techniques such as COB, TAB, (μ)BGA and others.

DYCOstrate® - C technology. The majority of today´s applications are simple rigid boards. Therefore, the so-called DYCOstrate® - C (commercial) technology is developed, in which an FR-4 buttered Cu-foil is laminated onto one or both sides of a standard FR-4 core. Besides plasma-drilled blind vias ordinary mechanically drilled through holes are also applied. DYCOstrate® - C enables the low-cost manufacture of PWBs which are densely wired.

Plasma formation of through holes. Plasma drilling enables the production of PCB´s without rejecting conventional PCB processing. Usual photo resist technique is applied to produce the Cu mask prior to plasma etching of the organic base material of the DYCOstrate® foil. Base materials typically used are polyimide and FR-X materials. The isotropic etch effect leads to an inherent undercut which is nearly levelled after Cu plating and Ni/Au deposition. „Drill hole" diameters of 75μm and less are recently produced (Fig. 6).

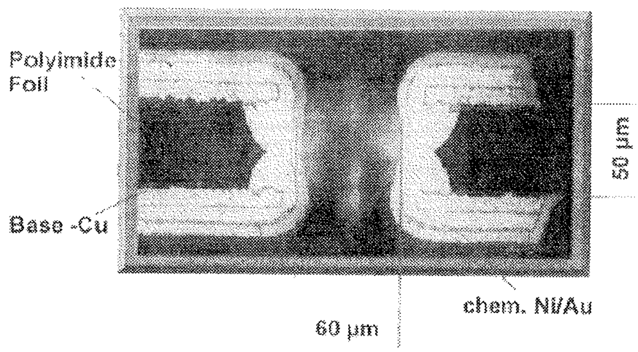

Fig. 6: Cross section through a plasma etched through via after Cu plating and Ni/Au deposition.

Plasma formation of blind holes. The former Dip-In-Hole assembling technique has been widely replaced by the current Surface Mount Technology. Coupled with this development the production of blind vias has become more and more important for the connection of two related layers. An outstanding feature of DYCOstrate®- plasma drilling is: The production of blind vias is technically easy (Fig. 7). Multilayer build-ups (Fig. 8), for instance, can be completely new designed by applying the DYCOstrate® process.

Both, minimum-sized hole diameter and the technically easy production of blind vias makes plasma etching a promising tool for future PCB manufacturing.

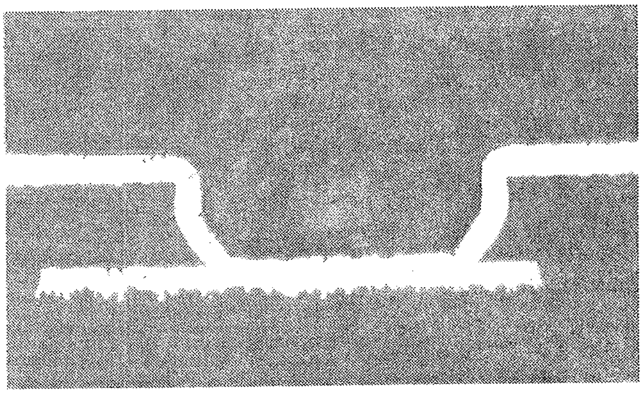

Fig. 7: Cross section through a plasma etched blind via after hole forming and Cu plating.

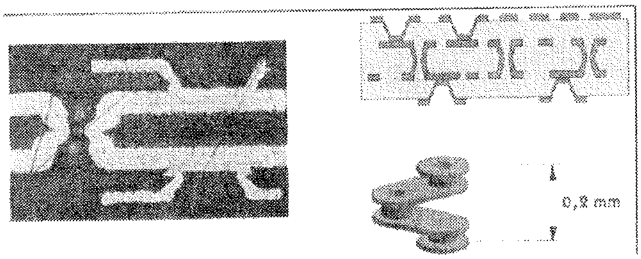

Fig. 8: Micro cross section of DYCOstrate® 4D interconnect.

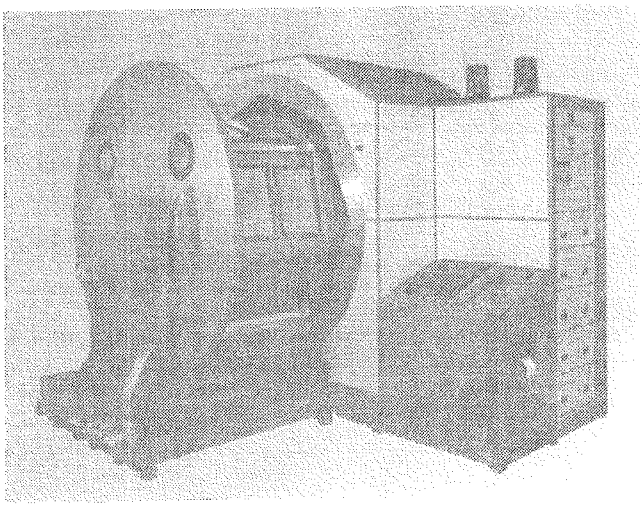

Fig. 9: Plasma plant MK IV with a capacity of six 18"x 24" panels - the world biggest plasma drill equipment.

Technics Plasma GmbH has built plasma drill equipment with different capacity. The currently world biggest plasma drill equipment MK IV has a capacity of six 18"x 24" panels per run (Fig. 9). The drill process lasts for approx. 25 minutes. As for the microwave batch ashing the plasma drill process is highly economical, based on 1-shift operation the operating cost per panel are 0.70 US $ only.

3.2 Substrate Cleaning prior to Wire Bonding and Encapsulation

Plasma cleaning of lead frames and Ball Grid Arrays (BGAs), especially Plastic-BGAs, has become a major focus for improving the reliability of high density interconnections.

Plasma treatment after die bonding has a dramatic influence on both the bonding yield and the bonding strength. Bonding yields with and without plasma cleaning are shown in Fig. 10 as a function of the ultrasonic energy used. Fig. 11 shows the strong improvement of bond strength after plasma cleaning with oxygen. Plasma removes here organic deposits that migrate to the bond pads during the curing process following die attach. The metal surface becomes highly activated and a solid metallurgical bond is much more easily formed. The entire process flow in IC packaging following the final wafer test is depicted in Fig. 12. The plasma treatment prior to wire bonding also activates the substrate for the encapsulation step. Adhesion of epoxy moulds used for encapsulation is strongly improved and their delamination in operation, called pop-corn effect, can be prevented.

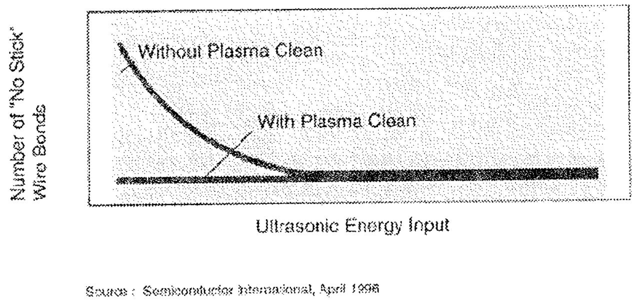

Fig.10: Effect of plasma cleaning for low ultrasonic energy input.

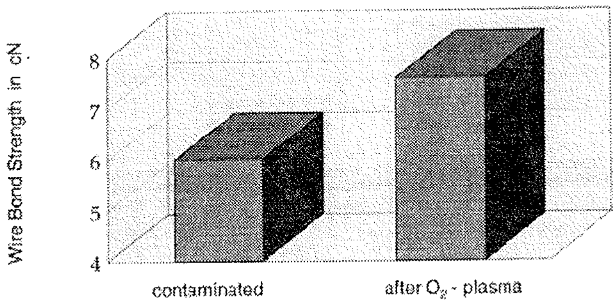

Fig.11: Optimum wire bonding through plasma cleaning.

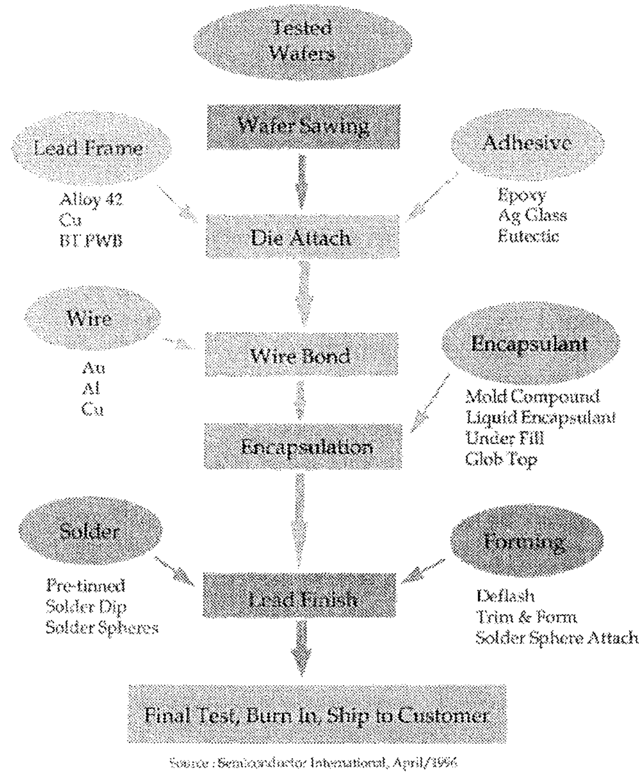

Fig.12: *Process flow in IC assembling*

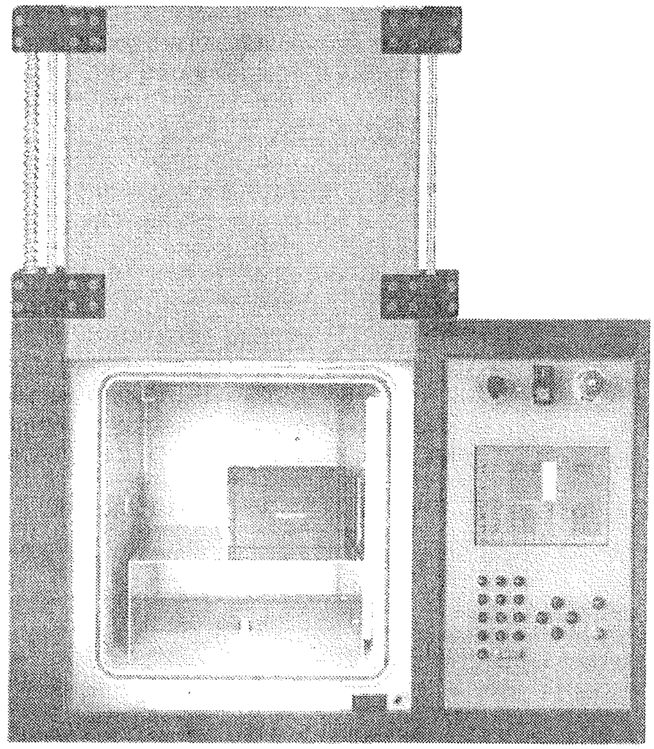

Fig.13: *Plasma cabinet 400 Inline for cleaning of lead frames and PBGAs*

Plasma processing in IC packaging increases in importance with the appearance of new lead frame materials, such as BT resin substrates or lower cost material. These substrates cannot handle the conventional wire bonding temperatures of 175-190 °C for long. High lead count devices will be packaged in these materials. Plasma cleaning will enhance the ability to lower the bonding temperatues maintaining high yields and high quality of components in the low cost BGA scenario.

Technics Plasma GmbH has built a lead frame and BGA cleaner shown in Fig. 13. The process chamber has a volume of 64 liters, the front-door opens vertically. This plasma system operates computer controlled and can be fully integrated in automated assembling lines.

4. Conclusions

The applications described in this paper demonstrate clearly the power of this technology for wafer fabrication as well as for PCB manufacturing. The low pressure plasma process works extremely reliable and cost-effective. Technics Plasma equipment features superior microwave technology showing a lot of advantages: electrodeless microwave power supply, very high yield and damage-free process.

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