

## Low-Cost Adhesives for Temporary Substrate Support

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### Abstract

Temporary adhesives are a key part to 3DIC integration. Choosing the right adhesive is critical as it defines your process, tooling needs, and by virtue of its chemistry, will control throughput and yield. Although several products and tooling exist in the market, few offer a clear path to achieve HVM at an affordable cost. A wide range in materials and processes are available, most which can be tailored to a specific design or tooling objective. Multiple options in adhesives allow grinding and polishing to <20um, protection during backside processing (e.g. TSVs), thermal resistance to >400C, CVD acceptance, and rapid removal with cleans on a film frame. Using batch processing, throughput is increased by a factor of 5 while cost is reduced by 50%, suggesting a COO that is 10% relative to current practice. Instituting simple materials and processes matched to a customer's design will provide benefits beyond cost savings, including "green factory" certification. This presentation reviews several current practices in the market and contrasts these options with alternative low-cost adhesives and processes that are tuned to a customer's product design and tooling. Examples include excerpts from handling thin substrates in semiconductor, solar, and TFT/LCD fabrication lines.

Key words: adhesive, thinning, bumping

### I. INTRODUCTION

Low-cost adhesives may be realized in many ways, varying from simple water-soluble systems, which eliminate solvent cleaning steps to those, which may be used with porous carriers to allow batch processing. These adhesives may be incrementally lower in cost as a material, yet their greatest benefits may lie in simplifying processes and exhibiting properties not currently available on the market. For example, although solvent cleans is ubiquitous at all levels of semiconductor manufacturing for PR and adhesive removal, aqueous-based approaches are being considered for lowering cost and as enabling for new technologies. Water-soluble adhesives and cleaning methods are being recognized as compliant for new chip and wafer stacking practices similar to that described in Fig. 1 for photoresist stripping (bumping).

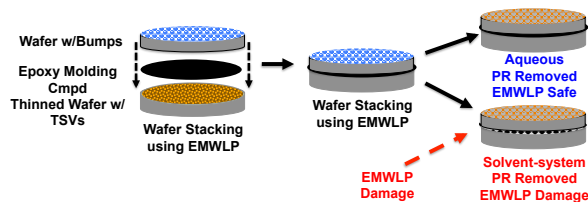


Fig. 1. Aqueous PR removal during bumping as an enabling practice for wafer stacking using EMWLP.

At the time of this publication, options for encapsulation/bonding in chip and wafer stacking is being investigated using various compression molding practices and materials, including epoxy. This method, identified as 3D embedded micro wafer

level package (EMWLP) eliminates wire bonds and bumps to achieve a low-cost package [1-5].

#### A. Temporary Bonding (Review)

Although wafer thinning and backside processing may be integral to 3D packaging, the choice in materials and methods of de-bonding can vary dramatically. All current technologies involve a temporary adhesive and a carrier to support a thin substrate to below 20 um. Of the common wafer support practices, an adhesive bonded carrier is the most reliable, able to support thin substrates and exhibit the chemical and thermal resistance necessary for backside work (Table 1).

Table 1. Options and their properties for thin wafer support.

| Method                  | Wafer Thick (um) | Chem & Therm Resistant | Single Wafer or Batch | Backside Process Support |
|-------------------------|------------------|------------------------|-----------------------|--------------------------|
| Tape                    | >50              | No                     | Both                  | No                       |
| Vacuum Chuck            | >50              | No                     | Single                | No                       |
| Adhesive Bonded Carrier | <25              | Yes                    | Both                  | Yes                      |

The use of carriers offers good surface planarity, measured as a low TTV, and are believed to reduce both internal stress and wafer bow during grinding [6-9]. Liquid spin-on forms of adhesives offer easy control of TTV when the coating is applied to solid and smooth (native) or patterned wafers. In this condition, acceptable uniformity during thinning may be achieved if the TTV is  $\leq 0.5\%$  [10-11]. Once thinned, the adhesive continues to hold the substrate

in place through backside processing, a series of steps that may include TSVs, metallization, and extend to dicing. A common feature to the use of temporary adhesives with carriers includes two active stages, namely, bonding and debonding (Fig. 2).

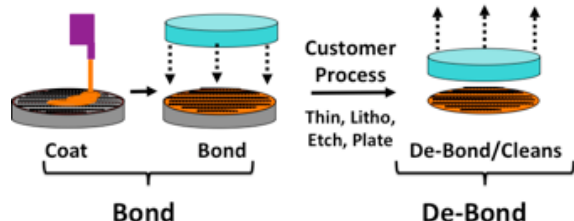


Fig. 2. Two active stages to the use of any temporary adhesive and carrier, bonding and de-bonding. Cleaning is included in the de-bonding practice.

Products used in the marketplace include the following: a) rubber/olefinic [12-13], b) acrylic [14], c) silicone [15], d) polyimide, and e) rosin-urethane [16]. Although these chemistries vary, their methods of application and bonding are similar, namely, the material is coated onto the wafer, cured, and bonded to the carrier (Fig. 2). The main variance in performance and complexity is in their de-bonding (Fig. 3).

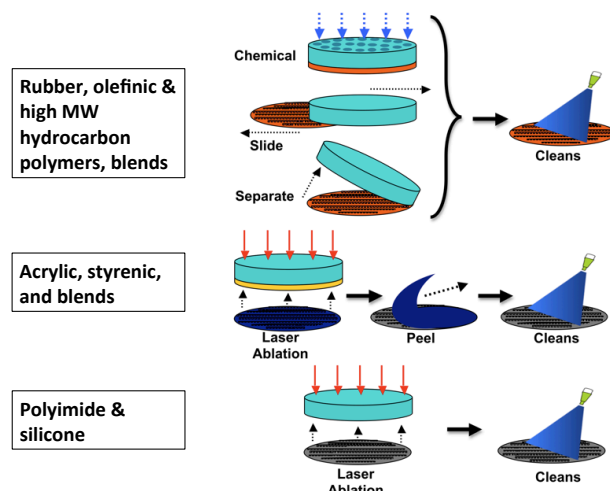


Fig. 3. Leading temporary adhesives commercially available at the time of publication. These materials vary according to their de-bond performance and complexity.

De-bonding of the rubber/olefinic adhesive is offered as three choices, including chemical dissolution through a perforated carrier, thermal slide, and separation of the carrier by the use of a reduced adhesion layer to an inner region of the carrier that has been previously prepared and masked. An acrylic-based temporary adhesive requires laser ablation of the interface between the carrier and adhesive and once removed, the remaining adhesive layer is peeled away from the thinned product wafer. Other options include the use of polyimide and

silicone adhesives, both using a similar ablative removal. All of these technologies incorporate a final cleaning step to remove adhesive residue from the product wafer.

### B. Thermal Resistance

We have reported on the highest thermal resistant polymer available in commerce, polybenzimidazole (PBI), formulated into several coatings and adhesives [17-19]. It is well known that several thermal resistant polymers exist in commerce. These systems include both amorphous and thermosetting. Several have been demonstrated alone or as blends for temporary applications and are shown in the following Table 2, PBI is identified #4.

Table 2. Thermal resistant polymers and their properties.

| # | Polymer                        | Cure Method | Thick (um) | Therm. Resist (°C) | Water Resist |
|---|--------------------------------|-------------|------------|--------------------|--------------|
| 1 | Epoxy                          | UV          | <20        | >275               | Yes          |
| 2 | Rubber                         | Evap.       | <15        | >250               | Yes          |
| 3 | Poly-phenylene                 | Evap.       | <10        | >330               | Yes          |
| 4 | Imidazole                      | Evap.       | <5         | >450               | Yes          |
| 5 | Biphenyl Sulfonate + Polyester | Evap.       | <10        | >300               | No           |
| 6 | Acrylic                        | UV          | <20        | <250               | Yes          |
| 7 | Silicone                       | Catalytic   | <10        | >300               | Yes          |
| 8 | PAI                            | Evap.       | <10        | >300               | Yes          |

Several polymers listed in Table 2 may be formulated to be aqueous soluble. The solubility can be tuned to be DIW soluble or detergent soluble such that it will prevent early digestion during slicing and dicing or during a pre-processing step.

### C. Vacuum Processing

One of the most challenging processes to overcome with a temporary polymeric adhesive is a simultaneous high vacuum with thermal condition. For most materials, reduced pressure conditions affect their physical chemistry properties by reducing the melting and boiling point. This applies to polymers, however, not all will express the same sensitivity. High vacuum conditions on materials at temperatures below their glass transition (Tg) will have less affect than if the temperature is raised to above that level. Therefore, crystalline materials should outgas lower when the thermal condition is below their Tg, and if amorphous, below their softening point (SP). This information may be applied by selecting a material with a Tg or SP above the process conditions, as described below for a CVD (Fig. 4).

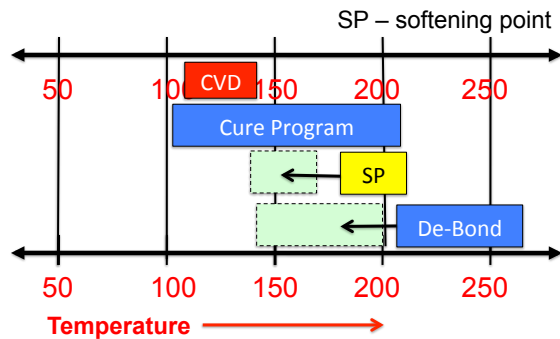


Fig. 4. Material selection using SP > process (CVD).

The addition of barrier materials may also be used to suppress the migration of gaseous by-products in the adhesive. Barrier polymers are macromolecules, which exhibit the ability to significantly restrict the passage of gases, vapors, and liquids [20]. These substances exhibit low permeability as expressed as the measured gas passing through a specific polymer film of given thickness per day at 1 atm pressure (cm<sup>3</sup>-ml/day-atm). Experiments indicate barrier values of 10% offer a measured benefit in support of CVD processes (Fig. 5)

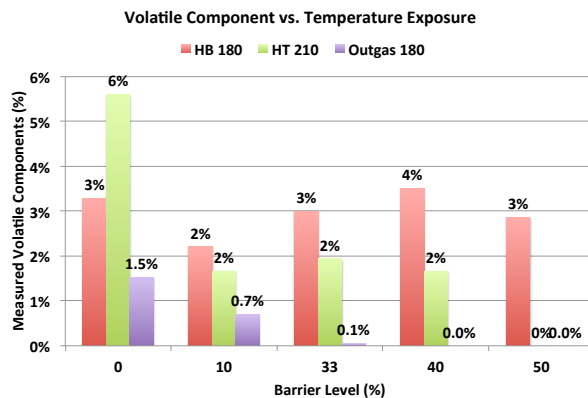


Figure 5. Outgas vs. barrier % in a CVD operation.

#### D. Cleaning

One of the most important properties of the wafer adhesive is its ability to be easily removed (cleaned) from the surface, leaving the substrate in a pristine condition. Usual cleans practices involve the application of solvents or aqueous mixtures followed by an alcohol or water rinse. Typical cleaning practices for 300 mm wafers uses a single-wafer cleaning tool with the flow described Fig. 6.

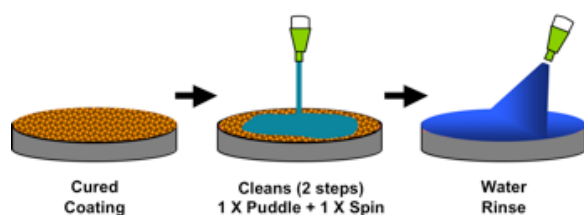


Fig. 6. Process flow for cleans following de-bond.

It is generally accepted that de-bonding and cleaning is preferred while the product wafer is supported on a tape (film frame). This practice requires cleaning and process to be fully compatible (safe) with the chemistry of the tape (Fig. 7).

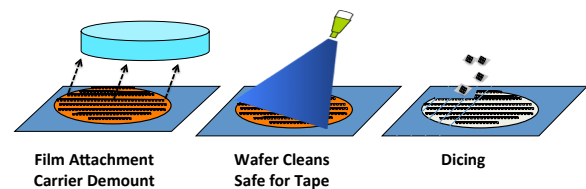


Fig. 7. Process flow for cleans while product wafer is supported on tape (film frame).

Most acrylic-type wafer taping media exhibits limited compatibility to those organic solvents used to clean/remove temporary adhesives described in Fig. 3. Many organic-solvent cleaning practices may use a special tool to maintain separation of the cleaning chemistry from the tape media. This activity is being investigated. In the case of aqueous-soluble adhesives, complete compatibility exists and no additional equipment would be necessary.

#### E. Aqueous Soluble

The primary reasons in using aqueous soluble adhesives include process simplification, material compatibility, cost reduction, and environmental safety. Whether it be cleaning with water or detergents, the chemistries are non-flammable, non-toxic, and do not generate evaporative material to trigger air permit requirements. Subtleties exist in aqueous cleans, and many believe it to be more challenging to control than organic solvents. Effective aqueous systems are built with additives that prevent irregularities during processing. Detergents are mixed with purified water. Ingredients in the detergent mix with species from the adhesive to prevent redeposition, inhibit corrosion, and stop scale build-up. These so-called detergents are complex and offer a balance in chemistry to deliver performance at the selectivity that is desired by the process.

Due to their inherent low-cost and no-waste generation, detergents are the material of choice where large substrates are being processed. Certain companies are providing aqueous-washable temporary coatings and adhesives with simple cleaners in concentrated forms for semiconductor and other challenging markets [21]. Mixing at 3-10%, filtering, and then heating is simple and consistent with current practice. Using detergents for stripping PR and temporary adhesives is the fastest way to reduce costs by as much as 50%, and to reduce or eliminate the need for waste management.

### F. Batch Debonding

For several decades, temporary adhesives have been used in mounting wafers to carriers, thinning, backside processing, and finishing by a batch debonding process [10-12]. Bonded wafers are assembled in a cassette and then immersed into the cleaning solution. Penetration occurs via conduction channels at the side and through a perforated carrier allowing breakdown of the adhesive. The adhesive gives way and demounting occurs with simultaneous cleaning in the same bath. Customers have established a fixture to separate the carrier from the product wafer without yield loss.

Perforated carriers remain in use; however, a new generation of porous substrates are being explored. These substrates are designed to allow greater fluid contact to the adhesive and aid in batch debonding. Some materials exhibit smooth surfaces with Rq values of 1um or less and flatness within 10-25um (Fig. 8).

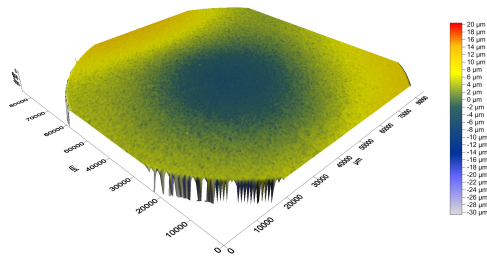


Figure 8. Flatness of a porous carrier, used to demonstrate batch de-bonding processes.

### G. Low Cost of Ownership

When conducting comparisons of one technology vs. another, we use a relative COO comparison is made with assumptions. Starting with SEMI E35 [22], a screening comparison is conducted as a ratio between  $COO_2$  and  $COO_1$  and canceling many of the variables due to the assumptions of similar yield, internal costs, scrap, life, and maintenance (Fig. 9).

| Item | Definition         |
|------|--------------------|
| F\$  | Fixed Costs        |
| R\$  | Recurring Costs    |
| Y\$  | Yield Cost (scrap) |
| L    | Equipment Life     |
| T    | Throughput         |
| Y    | Composite Yield    |
| U    | Utilization        |

$$COO = \frac{F\$ + R\$ + Y\$}{L \times T \times Y \times U} = \frac{\text{Costs}}{\text{Product}}$$

$$\frac{COO_2}{COO_1} = \frac{\text{Technology 2}}{\text{Technology 1}}$$

Fig. 9. Variable identity from SEMI E35 & comparison.

## II. EXPERIMENTAL

### A. Materials

For subsequent analytical testing, quartz substrates as are chosen and prepared at Daetec along with 100-IMAPS.2012.AZ.Daetec.F.docx

200 mm (4-8") silicon wafers (1-0-0, ~525 µm) re-manufactured from Wollemi Technical, Inc. (Taiwan, www.wollemi.com.tw). Materials used include commercially available spin-coated adhesives and other developmental products produced at Daetec [23]. UV-cure applications are conducted with n,n-dimethylacrylamide (DMAA) available from San-Esters and various photoinitiators under the tradename *Irgacure*, available from BASF. One example that is frequently used in Daetec's labs, includes Irgacure 2022 (BAPO/α-hydroxykeone). Solvents and other chemicals considered to be common to a development laboratory are available.

### B. Equipment

Coatings are produced on a Brewer Science, Inc. CB-100 spin-coater, while spray and encapsulation uses custom tooling designed at Daetec. Metrology data is generated by a XP-1 stylus profiler, AFP-200 atomic force profiler, and a Xi-100 optical profiler [24]. Where applicable, equipment settings include a 5 mg stylus load, minimum 4 mm distance, and speed of 0.5 mm/sec. Typical I-V plots are produced to compare trends and to study breakdown voltage of the protective film. Analytical equipment used in material characterization includes SEM (Hitachi 4700), Energy dispersive X-ray Spectroscopy (EDS), FTIR with ATR (Spectrum 100, DGTS detector, ZnSe coating accessory, Perkin-Elmer www.perkinelmer.com). Modified thermogravimetric test methodology for outgas is conducted by typical laboratory scales (+/- 0.1mg). UV cure equipment includes the Intelli-Ray 400 microprocessor controlled light curing system (Uvitron International, www.uvitron.com).

## III. RESULTS

### A. Thermal Resistant UV-Cured PBI

PBI polymer is prepared in DMAC (6-13%) and spin-coated onto silicon wafers cured according to Table 4 and measured for thickness. A second set samples containing a reconstituted form of PBI polymer is prepared as a fine powder. PBI "recon" powder is used for non-DMAC solvents or when performing UV curing, using the process indicated in Fig. 10, cured by UV, thermal outgas 250C 5min., and tested by lab TGA (Fig. 11).

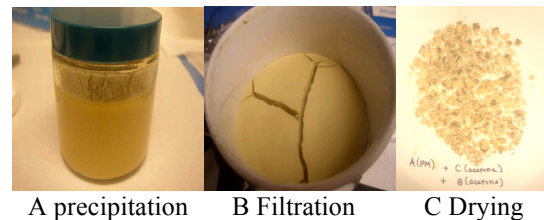


Fig. 10. Process of preparation of PBI "recon", a reconstituted version of PBI in UV applications. PBI dope (26% in DMAC) is mixed with a non-solvent to begin precipitation (A). The precipitate is



filtered/washed (B), removed and dried (C).

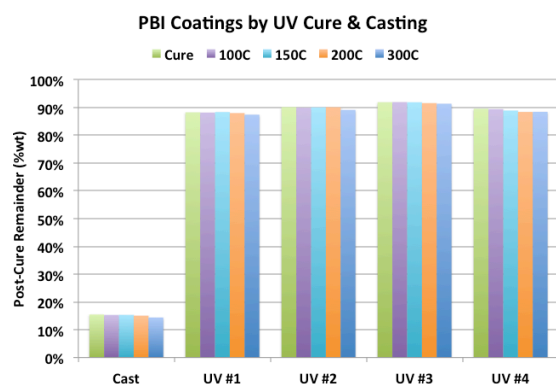


Fig. 11. UV cure results of PBI adhesive, exhibiting thermal resistance to 300C (4 series of bars on right). Evaporative (casting) is shown at left (<20% solids).

### B. Aqueous Soluble Adhesive

Aqueous soluble adhesives (e.g. sample PCA120106A) were formulated to achieve >300C resistance and exhibit no measurable outgas by gravimetric analysis. The system was designed for rapid cure using UV (<60sec, 400w). In the following condition a coating is applied and may be fixed by a thermal exposure (optional) then followed by UV cure. The system uses a post cure thermal exposure to eliminate outgas (Fig. 12).

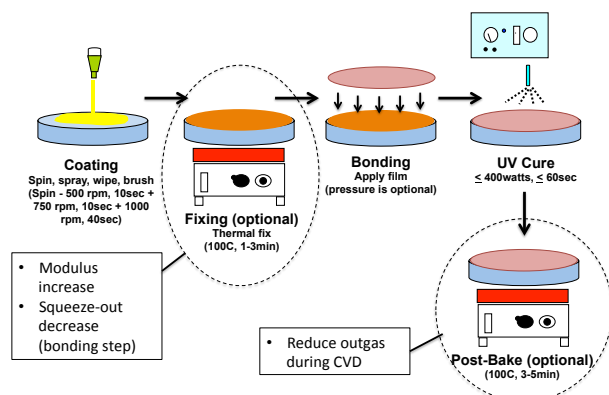


Fig. 12. UV cure system PCA120106A with post thermal exposure for CVD processes. Adhesive is detergent soluble.

The cured adhesive PCA120106A can be applied anywhere from 5-300um, cured in seconds, and be processed to >300C without damage or observed changes in the integrity of the bond or other conditions. When bonded to porous substrates the de-bond and cleans condition occurs within 15min. This technology is currently being introduced to processes requiring aqueous compatibility. Cost calculations in terms of relative COO are given below.

Table 3. Details of variables for COO<sub>2</sub> vs. COO<sub>1</sub>, aqueous adhesive vs. rubber adhesive.

| Item | Definition         | COO <sub>2</sub> vs. COO <sub>1</sub>                                    | Explanation   |
|------|--------------------|--|---|
| F\$  | Fixed Costs        | $F\$_1 = 5.1 \times R\$_1$<br>$F\$_2 = -0- \text{ or } 1.2 \times R\$_2$ | SW tool as Materials Cost<br>Use onsite tool or batch |
| R\$  | Recurring Costs    | $R\$_2 = 0.75 \times R\$_1$  | Materials Cost #2 (AQ)<br>= 0.75 X #1 (current)       |
| Y\$  | Yield Cost (scrap) | $Y\$_2 = Y\$_1 = 0$  | No loss for each tech.                                |
| L    | Equipment Life     | $L_2 = L_1$  | Same life   |
| T    | Throughput         | $T_2 = 8.3 \times T_1$   | batch vs SW = 8.3 X T <sub>1</sub>                    |
| Y    | Composite Yield    | $Y_2 = Y_1$  | Same yield  |
| U    | Utilization        | $U_2 = U_1$  | Same maintenance                                      |

Assumptions: materials cost of aqueous system is 0.75 X rubber system (i.e. 0.75 X R\$<sub>1</sub>); throughput for existing rubber system is ~12wph, aqueous uses a batch flow ~100wph (i.e. 8.3 X T<sub>1</sub>); new tool cost of rubber system ~\$3m and represented as material's costs over 3yrs (~\$590K) is F\$<sub>1</sub> = 5.1 X R\$<sub>1</sub>, aqueous system is F\$<sub>2</sub> = 0.9 X R\$<sub>1</sub>. The aqueous system exhibits options to use existing wet bench operations or install a new wet bench.

$$\frac{COO_2}{COO_1} = \frac{T_1(F\$_2 + 0.75R\$_1)}{8.3T_1(5.1R\$_1 + R\$_1)}$$

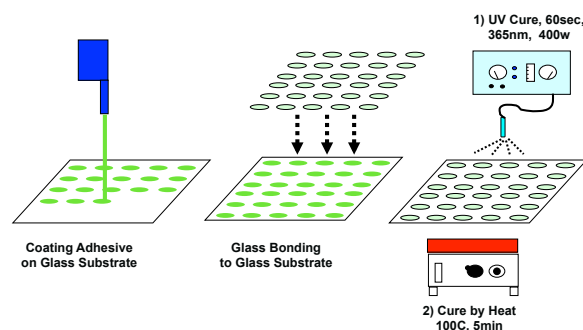
Calculate for use of  
existing tool  
(F\$<sub>2</sub> = -0-)  
or new tool  
(F\$<sub>2</sub> = 0.9R\$<sub>1</sub>)

| Comparison of<br>COO<br>Technologies | Use Existing<br>Wet Bench<br>(Batch) | New Wet<br>Bench<br>(Batch) |
|--------------------------------------|--------------------------------------|-----------------------------|
| COO <sub>2</sub> /COO <sub>1</sub>   | 1.5%                                 | 3.2%                        |

The projected relative COO of the aqueous system vs. that of a rubber-based adhesive is expected to be between 1.5-3.2%. Using these values and similar comparison between technologies, the payback period is about 1month (with throughput) and between 4-10months without consideration of throughput.

### C. Aqueous Washable Bond for Panel Glass

Same properties as item in (B). In the following condition a thick coating (~300um) is applied between two glass pieces and UV cure. The system uses a post cure thermal exposure to eliminate outgas and is washed by DIW or detergent (Fig. 13).



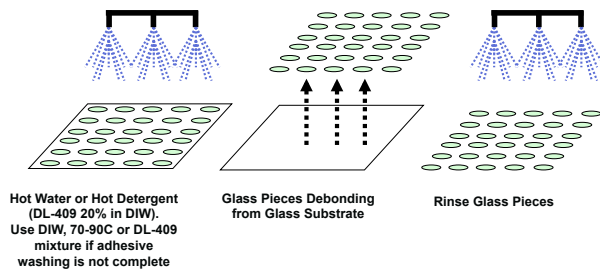


Fig. 13. Panel glass attachment with aqueous soluble adhesive, UV cure, customer processing, DIW wash.

#### D. Peelable (Detach) Bond for Flexible Substrate

Same properties as item in (B), not necessarily aqueous soluble. Multi-soluble material adhesives (e.g. sample PCA12130 series) were specifically designed for properties of modulus and adhesion to allow processing of a flexible panel material and removing it by simple peeling when finished. The processes are shown in the following two diagrams.

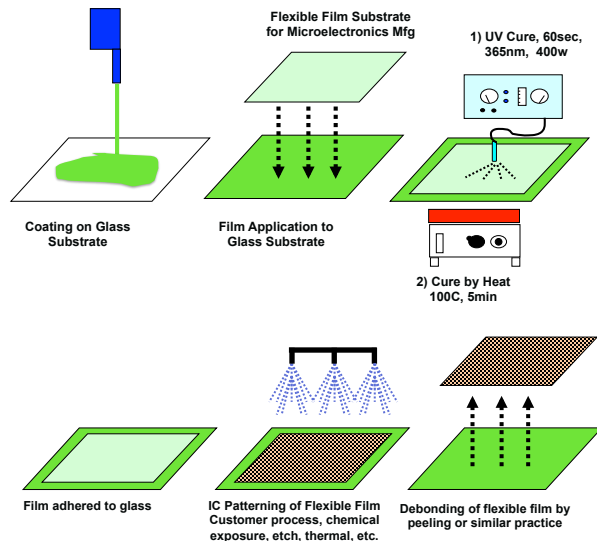


Fig. 14. Flexible substrate attach to panel glass by adhesive, cure, customer process, peelable removal.

#### IV. DISCUSSION

The use of adhesives for temporary mounting of chips or wafers, glass pieces or flexible substrates to a variety of substrates are being investigated worldwide. Achieving this activity in the simplest manner to meet processing conditions and eliminate the need for organic solvents will dramatically reduce costs. COO calculations have been conducted on several applications with similar results as that shown in this publication, providing savings >50% or more as compared to the existing product.

Continued introduction of aqueous soluble systems for use in temporary bonding applications provides not only a cost savings, but also enables the compatibility to new technologies. Aqueous soluble adhesives are available to apply to substrates for temporary bonding, meeting thermal resistance

>300C and complete cleaning from exotic metals and irregular surfaces. Using porous carriers allow new COO options not available with more difficult to remove adhesives.

#### V. CONCLUSIONS

This paper introduces the use of low-cost adhesives in commerce for semiconductor and panel-making endeavors. The use of aqueous soluble adhesives and cleaners allows fabrication facilities to reduce costs while enabling the use of new technologies. New technology options include EMWLP and other potential compatible driven materials processes.

#### ACKNOWLEDGMENT

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