

Fabrication of 3-D microstructures with permanent dielectric dry film

Tobias Baumgartner *, Karin Hauck*, Kai Zoschke*, Michael Töpfer*, Hidetaka Uno**, Werner Liebsch***, Hao Yun+, Mats J. Ehlin +, Karl H. Dietz +

* Fraunhofer IZM, Gustav-Meyer-Allee 25, 13355 Berlin, Germany

** Du Pont Kabushiki Kaisha., Sanno Park Tower 11-1, Nagata-cho 2-chome, Chiyoda-ku, Tokyo 100-6111; Japan

*** DuPont de Nemours s.a.r.l., Rue General Patton, Contern, L-2984 Luxembourg

+ DuPont Electronic Technologies, 14 TW Alexander Drive, Research Triangle Park, NC 27709, USA

tobias.baumgartner@izm.fraunhofer.de, karin.hauck@izm.fraunhofer.de, kai.zoschke@izm.fraunhofer.de,
michael.toepper@izm.fraunhofer.de, hidetaka.uno@jpn.dupont.com, werner.liebsch@deu.dupont.com,
HAO.YUN@usa.dupont.com, Mats.J.Ehlin@usa.dupont.com, Karl.H.Dietz@usa.dupont.com

Abstract

Smarter and cheaper encasing of devices is essential to bring packaging costs down. Two different types of packages are described in this paper. Both use wafer level processes which make them very cost effective.

In the first approach dry film resist functions as a glue and as a spacer at the same time. Frames of dry film resist are structured on the cap wafer by lamination and photolithography. This wafer is then bonded with a wafer-to-wafer-bonder onto the device wafer. Finally the stack is diced.

In the second approach, frames of photopolymer are structured on the device wafer. In the next step another layer of polymer is laminated on top of it. The second layer is then photo-structured to form the "roof" of the housing while the frame works as its "side walls".

Both packages can be used for encasing of for example SAW or BAW filters. The same processes can be used with different designs to create fluidic structures e.g. nozzles in ink print head or for medical application like lab-on-chip.

Introduction

Spin coating used to be the technology of choice for photo resist and polymer deposition in wafer level processing for many applications. However, driven by necessity of cost reduction many companies are looking for different ways of coating polymers and resists. The most promising one is lamination which has been successfully used for decades in PCB (printed circuit board) industry.. In the past those laminated films had, of course, strong limitations in terms of resolution since their development was specified for the needs of PCB production. Now advances in resist quality of these laminates in recent years arouse interest for many wafer level applications.

Applications of dry film photo resist

The largest benefits of lamination are the ability of very uniform coating and possibility to coat very thick layers (up to 120µm) with one single step. In addition the material consumption is reduced tremendously compared to spin-coating.

Therefore dry film is now used a lot for wafer level bumping. Dry film can be structured on a sputtered seed layer

and then be used for electroplating. Typical bumping metallizations are Cu-UBM (under bump metallization) with AgSn bump or Cu-pillar with Sn or AgSn cap. High-Pb bumping is also possible for all application still not under the lead ban.

Some dry films are even stable at reflow temperature of lead free solder for a short time. This makes them suitable for another bumping technology that uses screen printing of solder paste into resist. In this case a UBM is created e.g. by electroless-Ni on Al pads. Then resist is applied, photo-structured and developed. Solder paste is screen printed into the resist. The wafer then passes the reflow oven. Finally the resist is stripped. This process is explained in more detail in [1].

Applications of dry film permanent dielectric

With the success of dry film photo resist focus of new film developments in that field has now moved to permanent dielectric dry films. Here target thickness is again larger (10-100µm) than the one typically spin coated (<1-20µm).

These dielectrics can be used for several applications:

One is the use as a dielectric for standard RDL (redistribution layers) replacing spin-on dielectrics due to lower cost.

Fluidics is another field where these films are used. Dry film enables to create channel systems easily and cost effectively. This is a key feature for production of consumer products such as ink jet print heads or biomedical devices for single use such as lab-on-a-chip.

Further applications are housing of SAW filter, BAW filter or CCD camera chips. For SAW and BAW filter packaging dry film dielectric can be used in two different ways:

The first is to create a rim of polymer around the device. No polymer is allowed on the active area since this would have negative influence on the performance. Then a cover e.g. glass is bonded on top of the rim. The active area is now protected from ambient influence. Finally the devices are singulated.

The second approach uses the dry film laminate also to form the "roof". Again a rim of polymer is structured. Then a second layer of polymer is laminated on top of it, bridging for the rim on one side of the device to the rim on the other side

of it. The second polymer layer is then photo structured. In this case there is also the option to perform further process steps on wafer front side before the wafer is diced.

For CCD camera chip packaging the second approach is not suitable since a fully transparent cover is required. Otherwise the cover would destroy the sensor function. Therefore a similar process can be used as the SAW/BAW filter package described first. A polymer frame is used to bond a glass cover on top of a CCD sensor front side. This housing can protect the sensitive area during further process steps e.g. back grinding, etching, and creation of back side contacts. Finally after process and singulation the housing works as a protection against ambient influence. There is also the option to use the dry film dielectric to bond a lens stack on top of the CCD camera chip.

General description of dry film process

Dry film is delivered by material supplier e.g. DuPont as a three layer stack on a roll. The photo resist or polymer is the inner layer. It is protected by a polyester or a polyethylene foil, respectively, on the both sides. The polyethylene foil is removed before lamination on a substrate.

There are different types of laminators:

The simplest laminators are of roller type. Here the substrate is fed through two heated rolls. The resist is laminated by one of them or in case of double side lamination by both of them. Resist has then to be cut manually after lamination.

There are also more advanced types of laminators: One type pre cuts the resist and then puts it on to the wafer in a similar way like a wafer-to-wafer-bonder works.

In another one the wafer is put on to a heated chuck by a robot. The setup is schematically shown in fig.1.

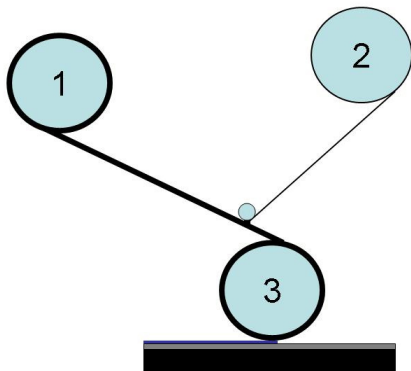


Fig.1. Schematic drawing of dry film lamination.

Roll no.1 is carrying the dry film as delivered by the material supplier. The polyethylene foil is removed and collected on roll no.2. Roll no.3 laminates the resist onto the wafer (grey) that is placed on the heated chuck (black). A heated knife cuts the resist after lamination around the wafer edge. The wafer is then put back into the carrier by a robot.

Another roll is collecting the unused resist. It is not shown in the drawing.

For the test described in this paper a Leonardo system from MicroControl in Milan, Italy was used. It uses the principle just explained.

After lamination the polymer or photo resist is exposed and developed.

Sample built-up (general)

The samples described in this paper were built up with a permanent dielectric dry film that is commercially available from DuPont Electronic Materials under the trade name PerMX.

First samples were dedicated for adhesion testing. PerMX dry film was laminated on to 8 inch Si wafers with a Leonardo laminator from Microcontrol. The film was then exposed with a Suss MicroTec MA200 mask aligner. The cover polyester foil was removed. Then the wafers were post exposure baked for 240s at 95°C. Development was done in a tank of PGMEA followed by PGMEA and IPA rinse.

Sample built-up for adhesion testing

Polymer columns were created on different surfaces. Adhesion was then qualified by shear testing. In a first step polymer columns with round or square shape, respectively, were tested for adhesion on SiO₂ surface while exposure dose and post development bake were varied.

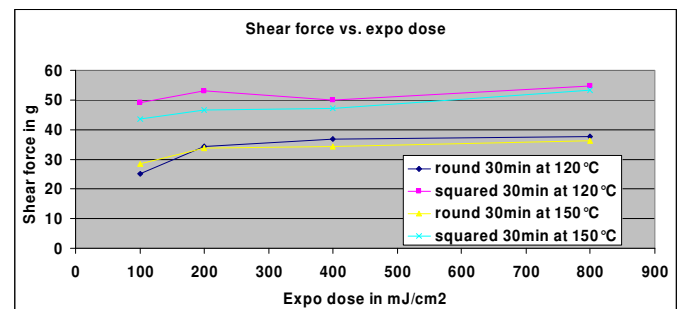


Fig.2. Adhesion polymer columns measured by shear testing (Adhesion vs. exposure dose and post exposure bake)

Fig.2 shows the result of this test: The adhesion varies with shape of the structure. This is due to the different size of contact area. The adhesion at 100mJ/cm² exposure dose is lower than those at higher exposure doses. This indicates that 100mJ/cm² is not enough to reach full cross linking. Once the polymer received a minimum dose of 200mJ/cm² adhesion does not increase with increase of exposure dose.

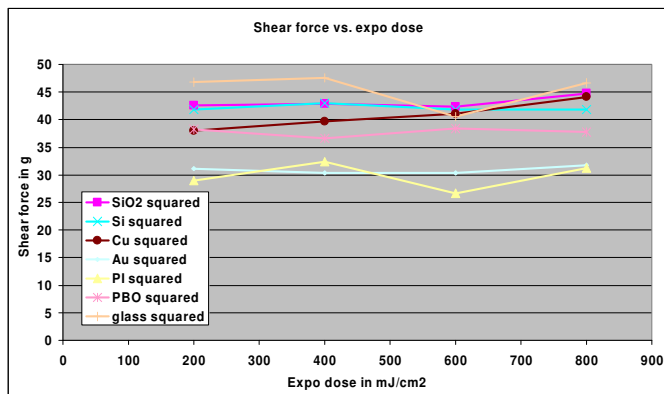
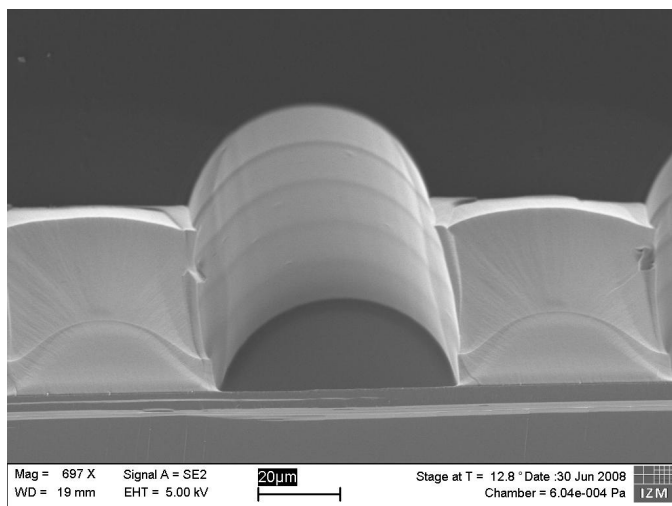


Fig3. Adhesion of polymer columns on different surfaces measured by shear testing (Adhesion vs. exposure dose)

In a second test adhesion of polymer columns on different surfaces was qualified again while exposure dose is varied. Fig.3 is showing the results. Here differences in adhesion on different materials can be observed. Lowest adhesion is seen on Polyimide and sputtered Au. The highest adhesion does PerMX have on Si, SiO₂ and glass, respectively.

Multi layer built-up

Dry film material allows lamination of several layers on top of each other and afterwards photo structure them. This enables to reach higher thicknesses than 14μm, 20μm or 50μm, respectively, which are the commercially available thicknesses of PerMX3000 material. It's also possible to combine layers of different thicknesses to reach the desired thickness for example one layer of 20μm and one of 50μm to form a layer of 70μm thickness. An example for such a multi layer stack is shown in pic1. The interface between the layers can still be recognized.



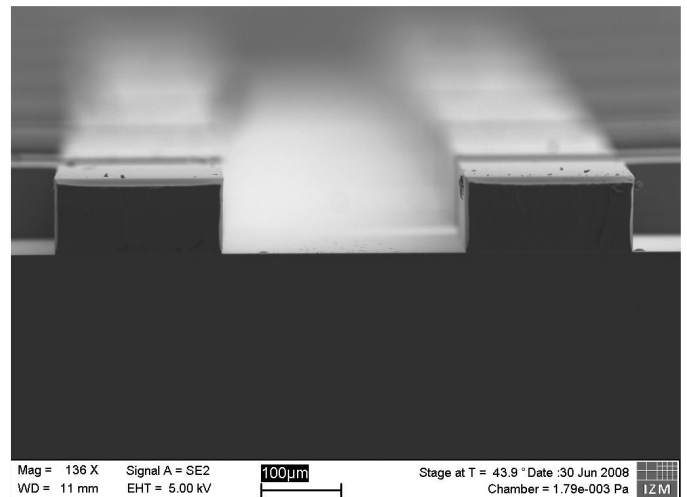
Pic.1. structured stack of five layers PerMX3020 (SEM picture of cross section)

Here five layers of PerMX3020 were laminated on top of each other with a Leonardo laminator system at a chuck temperature of 60°C. The process flow in detail works as follows: After lamination of the first layer the polyester foil was removed. The second layer was laminated on top of the

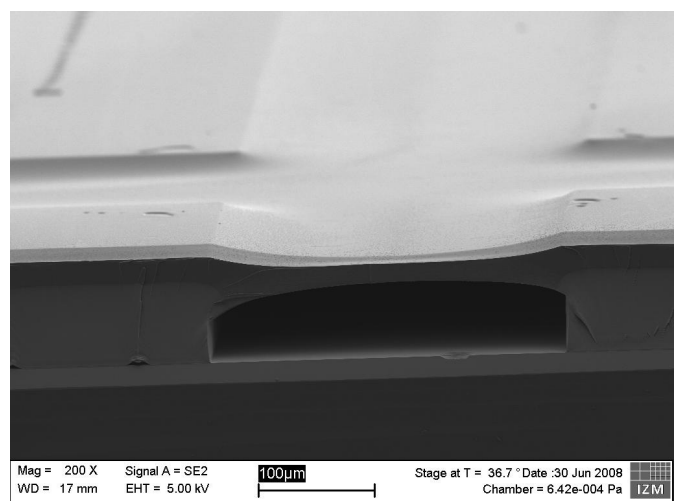
first one and so on until a five layer stack with total thickness of 100μm was reached. The 100μm thick layer was then exposed with 600mJ/cm² with a standard mask aligner from Suss MicroTec. After exposure a post exposure bake (PEB) of 4 minutes at 95°C was performed on a hotplate. Then the cover polyester foil was removed and the wafers were developed in a tank of PGMEA (propylene glycol mono methyl ether acetate) for 10 minutes. Tank development is followed by a rinse with fresh PGMEA and IPA (Iso propyl alcohol). Curing is done at 150°C for 30 minutes.

Channel structure built-up

The process flow for a channel built up starts with the structuring of side walls for the channels. Here again dry film is laminated onto the substrate. This can be also a multi layer process as described in the chapter before. The film is then exposed, baked and developed. A SEM picture of an example is shown in pic.2.



Pic.2. SEM picture showing the side walls that are used to create a channel structure



Pic3. SEM picture of cross section after application of laminated roof that creates a channel structure

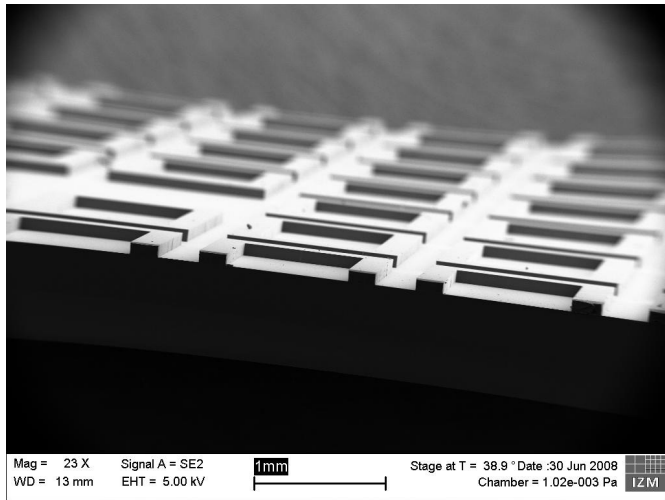
After the walls of the channel are built there is another lamination step. This time the film is laminated on top of the

walls tenting for channel side wall to the other. Lamination is followed by exposure, bake development and cure. An example channel structure can be seen in pic3

Housing structure built-up

For SAW/BAW filter chips and CCD camera sensor chips housing is needed that prevent the active area for contamination and attack by ambient influence. PerMX can be used to create those housing structures.

First step is to form a frame of polymer that works as side wall of the housing. These frames are produced of PerMX using the standard dry film process flow. An example for frames made of PerMX3020 is shown in pic4.



Pic4 SEM picture of DuPont PerMX frames on a Silicon wafer

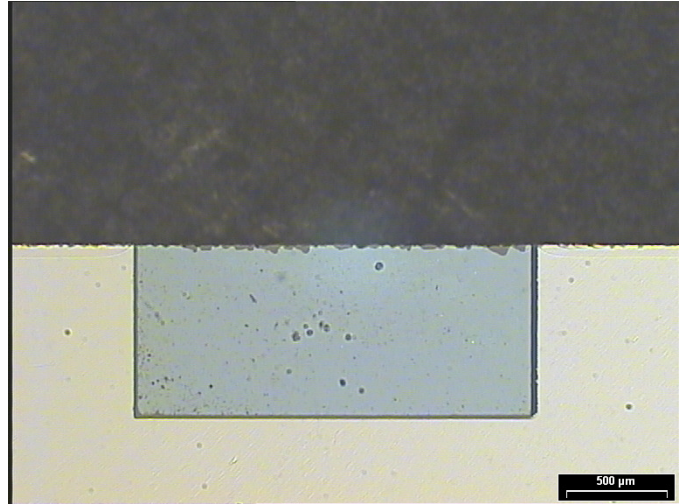
Next step is the bonding of a roof on top of the walls. This is done on wafer level with a fully automated wafer to wafer bonder from EV Group.

The silicon wafer with the structured PerMX was loaded as bottom wafer and the glass wafer was loaded as top wafer onto a rigid bond tool. In order to prevent touching of PerMX surface and glass wafer surface before starting the bonding process, three metal stripes were placed between the two wafers during the load procedure to act as spacer. Those three metal spacers are only interacting with the rear edge of the wafers in an angular distance of 120°. The two wafers were fixed with two mechanical clamp fingers, which apply a slight force onto the stack of the two separated wafers.

Now the bond tool with the clamped wafers was transferred into the bond chamber. The top and bottom bond chucks of the chamber were already pre-heated to 180°C, when the bond tool was moving in. After a certain wait time the chamber was evacuated and the separation flags were removed. In the next step a bond pressure of 40 N/cm² was applied to the wafer stack for a few minutes. Finally the bonded wafer stack was cooled until its temperature was less than 120°C before the vacuum was release and the bond tool was removed from the chamber. The complete chamber sequence time is in the range of 20 minutes.

After cooling down to room temperature on an external cool plate, the bonded wafer stack was separated from the bond tool and unloaded.

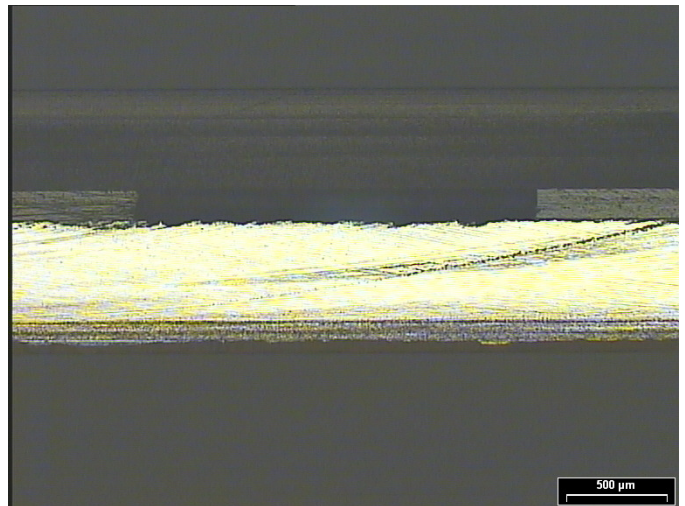
After bonding chips are separated by dicing. For this paper we have also diced throw a package to show a cross section .



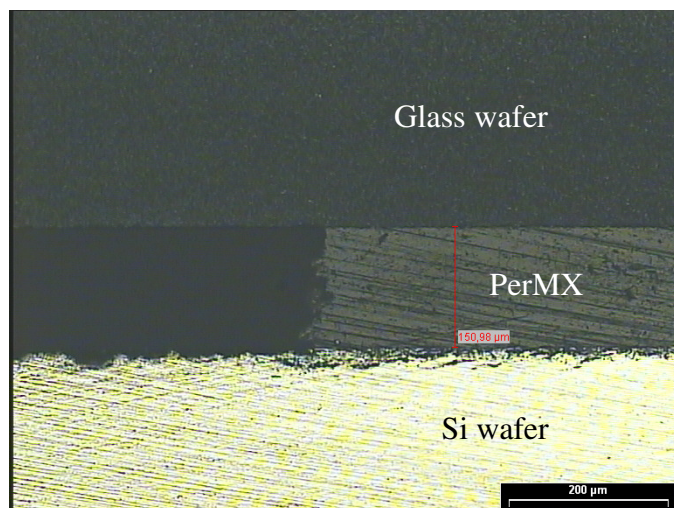
Pic5 diced housing with glass cover and PerMX side walls (View through the glass wafer)

The diced structure is shown from the top side looking through the glass wafer in Pic5. A cross section view of the complete package can be seen in Pic6. Pic.7 is showing a close up picture of the cross section.

We tested this built up with polymer layer thicknesses of 20μm, 50μm; 100μm and 150μm. Pic5, Pic6 and Pic7 are showing a 150μm sample.



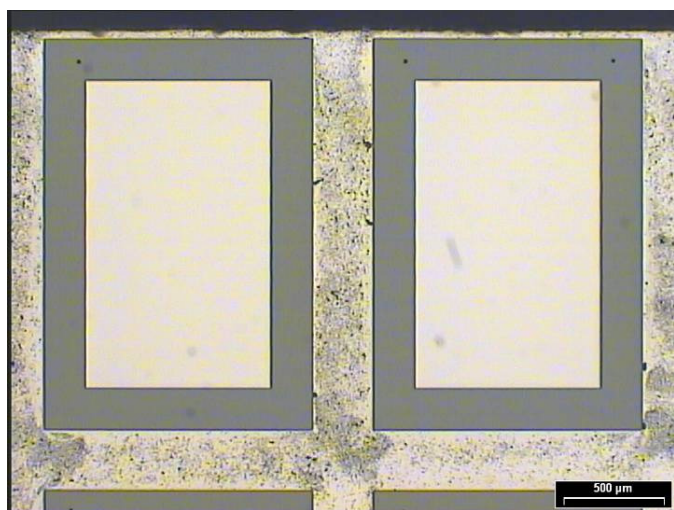
Pic6 diced housing with glass cover and PerMX side walls (Cross section)



Pic7 diced housing with glass cover and PerMX side walls (Cross section, close up)

Reliability testing

The package described in the chapter before was tested for reliability by thermal cycling as well as humidity storage at elevated temperature. The protective effect of the housing is illustrated in Pic8. Frames of PerMX were used to bond glass to Silicon wafers. On the Si wafer a sputtered Al layer was structured before. With a photolithographic process Al was etched where polymer frames are situated later. PerMX frames are therefore placed on SiO₂ surface. All parts free of polymer are covered with Al. In Pic8 can be seen that the Al inside the package is protected from corrosion while the one outside the package is already attacked.



Pic8 Test substrate after 24hours storage at 85%/85°C, view in optical microscope throw the glass wafer on top, Area inside the package is protected from corrosion

In the chapter before housing sample built up with polymer thicknesses of 50μm, 100μm and 150μm were described. These were diced to single chip size. Samples of each type were placed into thermal cycling from -55°C to 125°C and humidity storage at 85% and 85°C (Table1). They were qualified before and after testing by visual inspection.

Cycling was done up to 500cycles. Humidity storage was done up to two weeks. All samples passed these tests.

Table 1. Results of reliability testing

No	Test Description	Reliability Result
1	Humidity storage 85°C/85% for 24 hours	All samples passed
2	Humidity storage 85°C/85% for 168 hours	All samples passed
3	Humidity storage 85°C/85% for 336 hours	All samples passed
4	Temperature cycling -55 to 125°C for 100 cycles	All samples passed
5	Temperature cycling -55 to 125°C for 200 cycles	All samples passed
6	Temperature cycling -55 to 125°C for 500 cycles	All samples passed

Summary and conclusions

In this paper the use of dry film dielectric for several applications was described. Demonstrator samples for different applications were shown. The process flow of the sample built up was explained. The results of adhesion testing were discussed. Reliability test results of humidity storage as well as thermal cycling were shown. Based on all test and reliability results conducted and the easy processing of a dry-film, PerMX is a viable, cost effective material option for applications like packaging of SAW or BAW filter chip, housing of CCD camera chips, built up of channel structures for example for ink print heads or for biomedical devices for single use such as lab-on-a-chip.

References

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 "Printing Solder Paste in Dry Film -A Low Cost Fine-Pitch Bumping Technique"
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