New packaging technology enabling integration of Magnetics and Semiconductors in one component

Abel Pot, Application Development Manager, DSM Engineering Plastics, Geleen, The Netherlands

Dr. Horst Roehm, Technical Marketing Manager, NXP Semiconductors, Hamburg, Germany

Rinus v.d. Berg, Architectural and Industrial Designer, DSM Engineering Plastics, Geleen, The Netherlands

Dr. Tamim P. Sidiki, Innovation Program Manager, DSM Engineering Plastics, Sittard, The Netherlands

See-Wee Ong, Senior Application Development Support Engineer, DSM Engineering Plastics, Singapore

Frank van der Burgt, Product Development Engineer, DSM Engineering Plastics, Geleen, The Netherlands

DSM Engineering Plastics
Global Research & Technology
Urmonderbaan 22, 6167 RD Geleen
P.O. Box 604, 6160 AP Geleen
The Netherlands

Abstract

The continuous trend towards convergence and miniaturization is recently generating significant interest in new technologies for Electronics. This requires the integration of Semiconductors and Magnetics, two entirely different industries with different players in the value chain. In this paper, we demonstrate, a packaging technology which allows three dimensional stacking of Magnets and Semiconductors. We realized the integration of a Semiconductor chip - which provides protection against electro static discharge (ESD) – and a common mode filter (CMF) into one thermoplastic package. For the first time ever, this filter is integrated directly into the thermoplastic part which is used as the substrate, filter and housing at the same time.

Laser direct structuring in combination with Stanyl® ForTii™ as an ultra high performance, entirely halogen-free high temperature thermoplastic omits any wires for the realized coil, and also facilitates high flexibility in design and manufacturing, allowing ultra small footprints and the realization of components suitable for surface mount technology.

As an example of this new technology, we demonstrate a component which can provide full ESD protection and common mode filtering for a high speed USB2.0 interface.

ESD Protection

Impact of Moore's Law on ESD protection of advanced CMOS ICs

The continuous trend of feature-size miniaturization has enabled semiconductor manufacturers over decades to improve chip performance, reduce power consumption, and drive cost down by squeezing billions of transistors into a single IC. Despite all obvious advantages, there is one major disadvantage in miniaturization of sub- circuits: integration of sufficiently robust ESD protection.

Figure 1 shows the reduction of the total IC area for various technology nodes. The red boxes within each of these ICs indicate schematically the required area to implement a minimum 2-kV ESD protection into the IC [1]

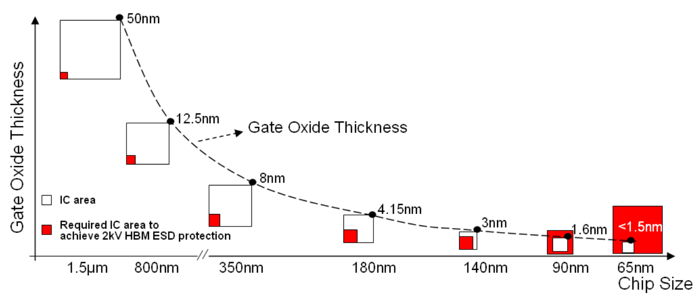

Figure 1: ESD considerations for advanced CMOS ICs

With each technology node the relative area required for ESD protection increases. The reason is that ESD protection scales with the area of the diodes and these diodes can not be shrunk at the same scale as transistors required for logic functions. It is obvious that for very advanced technology nodes there is a physical and economical limitation to integrate robust enough ESD protection. Advanced ICs are optimized for power consumption and speed, not for ESD protection. An optimization for ESD protection would blow up the chip above any acceptable limit.

Smaller feature sizes (channel length) related with thinner and smaller gate oxides drive down the maximum gate (e.g. for CMOS90 below 1.5V) and drain-source voltages (e.g. for CMOS90 <1.6V). Such ICs are very sensitive to over voltage and therefore especially sensitive to ESD discharges, which destroy sub- circuits already at very low ESD levels. As such, external board-level ESD protection becomes a must if developers of consumer/computer appliances want to build "CE"-compliant devices and furthermore want to prevent high field return rates due to ESD and other discharge issues. In general, one can say that today's ESD issue will become tomorrow's nightmare when even smaller feature sizes are applied.

External interfaces to other appliances are subject to ESD damage. In specific, higher speed, hot-plug interfaces such as HDMI, USB or Display port are most critical. Users can connect any sink or source equipment while at least one of the applications is still running, i.e. there is a supply voltage at the port. Needless to say, such a powered port will be affected by serious ESD issues. The question is not if, but only when the related transceivers (standalone or integrated) will be seriously damaged.

The high interface speed in conjunction with "hot plug" characteristics implies stringent requirements for an ESD protection solution, including:

- very high diode switching speed (nsec) and ultra low line capacitance (<1pF) can ensure signal integrity
- robust ESD protection without degradation after several ESD strikes
- low leakage even after several hundred ESD discharges

Based on main stream monolithic silicon technology, NXP Semiconductors provides ESD protection ICs fulfilling highest performance and meeting today’s and tomorrow’s requirements of OEMs in Electronics like:

- the required low-cost solution for the mass consumer and computer market
- ultra-low total line capacitance of below 0.5 pF (Silicon chip incl. bonding wires, package and any existing parasitic)
- no degradation even after thousands of high-level ESD strikes (IEC61000-4-2)
- a fast diode reaction time (nsec range) to ESD pulses
- highest integration
- full compliance with high speed interfaces such as HDMI 1.3, Display Port or USB3.0

EMI Filtering

High speed digital interfaces like HDMI, USB or Display Port are widely used in the mobile as well as in the computer and TV area [2]. As base for data exchange, all these interfaces use differential signals to exchange data which means, that two complementary signals were sent on two separate wires. As long as ideal differential signals are transmitted, no electromagnetic interference (EMI) will occur. Unfortunately, in a real electronic system phase lag between differential signals, potential differences between differential signals and rise (fall) time lag between differential signals leads to common mode signals and therefore to EMI. This affects other electrical circuits by electromagnetic conduction or electromagnetic radiation from external antennas. It is obvious that EMI has to be suppressed in electronic systems.

In systems with differential signals common mode filter (CMF) are widely used to suppress the unwanted EMI generated by common mode signals. Especially, if unshielded twisted pair (UTP) cables – which acts as an antenna for common mode signals - are used as interconnects between devices, the use of CMF is a must.

High Speed Interface Protection

Today, state of the art solutions are using separated devices for ESD protection and EMI filtering to protect the highly integrated silicon chips and to suppress unwanted EMI (Figure 2).

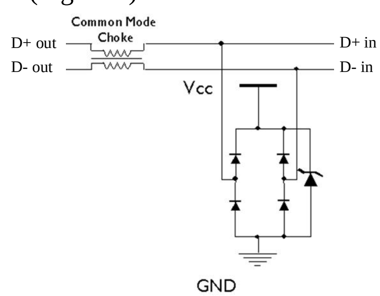

Figure 2: Schematic of a differential signal interface ESD & EMI protection

To overcome disadvantages of the discrete solution like space requirement, performance mismatch, inventory costs, etc. the integration of ESD protection and EMI filtering in one device is the next step, a straight forward approach.

Because CMFs are, in principle, built with wires winded around a ferrite core but on the other hand the ESD protection devices consists of diodes diffused in a block of silicon connected to a lead frame and covered by plastic the main challenge was to combine two different technologies in one package.

Global, cross-industry collaboration

Since this project involves entirely new technology, four companies have been working closely together to make it happen. The design of the package concept was proposed by DSM Engineering Plastics in The Netherlands, where a package was crafted enabling the integration of Semiconductors and Magnetics into one thermoplastic package based on injection molding. The injection molding of the package was done at NTM (NanoTechnology Mfg. Pte. Ltd.) in Singapore, the transfer of the EMI filter was achieved by Laser Direct Structuring (LDS) at Laser Micronics in Germany. In order to meet the high requirements of this technology to the thermoplastic, a new high temperature polyamide called Stanyl ForTii has been selected.

Market need for new package concept

OEMs in Electronics industry with their strong drive of application conversion seek for increased functionality integration and reduction of form factor to focus on PCB space and component count reduction. Since all external interfaces, in specific those operating at higher speeds such as HDMI, USB or Display Port, do require EMI filtering as well as ESD protection, two different components populate such interfaces and eat up valuable real estate on the PCB: ESD protection devices and EMI filters. From various discussions with leading OEMs, it is clear that a component which can integrate both these functionalities and at same time offers a space and component count reduction is highly appreciated and can solve some of the existing issues of OEMs realizing easier and denser application designs.

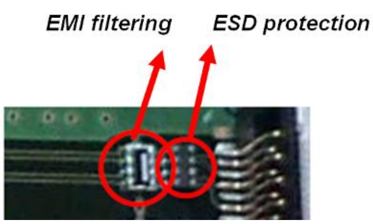

Figure 3: Optical microscopy of a typical external interface in Consumer Electronics using two individual components for ESD protection (first part after the interface pins) and EMI filtering (second component) in the electrical path on its way from the interface to the transceiver IC

We have designed and realized a package which integrates both these components into one package. This is a breakthrough technology which involves many industry first actions.

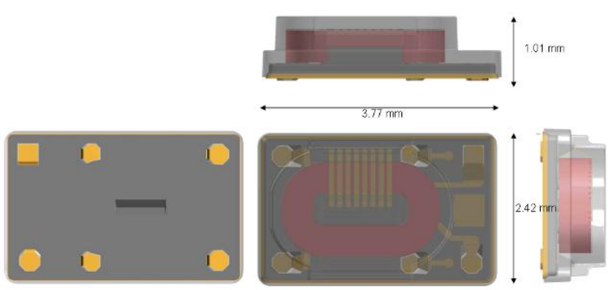

Figure 4: View of the package from the top, bottom and side showing total package dimensions

Figure 4 shows the sizes of the new package. With a total footprint of 3.77mm x 2,42mm x 1,01mm this is currently the world's smallest package integrating a fully EMI filters and an ESD protection for a high speed interface such as e.g. USB. The equivalent space reduction on the PCB is >75% by integration of these two components into one package. The small footprint in combination with low height enables PCB space reduction for OEMs.

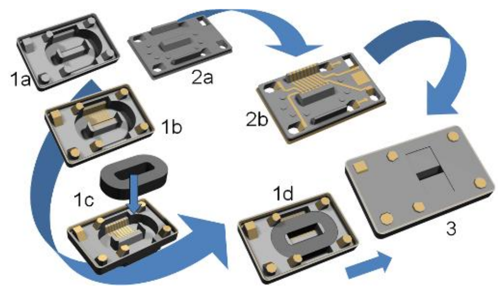

Figure 5: Schematics of manufacturing steps to realize a package integrating IC and magnet

Figure 5 shows the various manufacturing steps. In step 1a and 2a the top and cap layer of the package are molded in Stanyl ForTii, a high temperature polyamide suitable for lead free surface mount assembly due to high melting temperature Tm=320°C, a high glass transition temperature of Tg=135°C and a stiffness across a broad temperature range. From similar work in air cavity packages which are used for e.g. MEMS sensors it is well known that co-planarity is a key issue since it can lead to delamination of ICs mounted on lead frames. Due to the high stiffness and a comparable CTE (Coefficient of Thermal Expansion) values in the parallel and vertical flow direction, Stanyl ForTii was selected for this application. In specific the high stiffness at lead free reflow temperature range between 260-288°C makes Stanyl ForTii an unbeatable solution for such applications. Although reflow temperature is typically 260°C, we have also looked into a higher range up to 288°C in order to account for potential hot spots during assembly. Due to its high toughness before and after reflow (flexural strength), Stanyl polyamide family is one of few materials enabling such designs as applied in this concept. Any other halogen free material which would fit the temperature requirements of reflow soldering such as Liquid Chrystal Polymers (LCPs) are commonly known to be very brittle and would hence fail during later stages of package assembly.

After the top and bottom part are molded, the parts will be exposed to laser Direct Structuring (LDS) to transfer all electrical tracks (Figure 5: steps 1b and 2b). Later in this paper the process is described in more detail. At a next stage, chip and magnet are inserted (Figure 5: steps 1c and 1d) and finally the two parts of package are put together (Figure 5: step 3).

Package Molding

The specific design expertise at NTM allows design and building of tools and concepts with the help of mold simulation to seek application approval before starting with tool fabrication. 2D & 3D drawings are drafted to tooling specialist's to start with micro tool fabrication. The micro tools are fabricated using state-of-art machines like Kern Pyramid Nano, Charmilles Robform Die Sinker & Hauser Jig

Grinder for highly accuracy and finishing. Every process is precisely machined and quality controlled before the tool are being assembled.

The micro tool is set on the Battenfeld microsystem injection molding machine in the 10k clean room facility for better control and cleanness. The raw material is dried according to DSM material recommendation before injection molding in the micro tool starts. Micro molding process Engineer carefully process control the micro molding machine to ensure the parts are produced with high precision and stringent quality. Final inspection is supported by state of art measurement equipment and methodology to meet customer satisfaction.

Making use of the good rheological properties of the high temperature polyamide Stanyl ForTii, the cover and base parts could easily be molded in an injection molding machine fit for micro molding [3,4]. Even smallest details of the mold were easily transferred into the plastic.

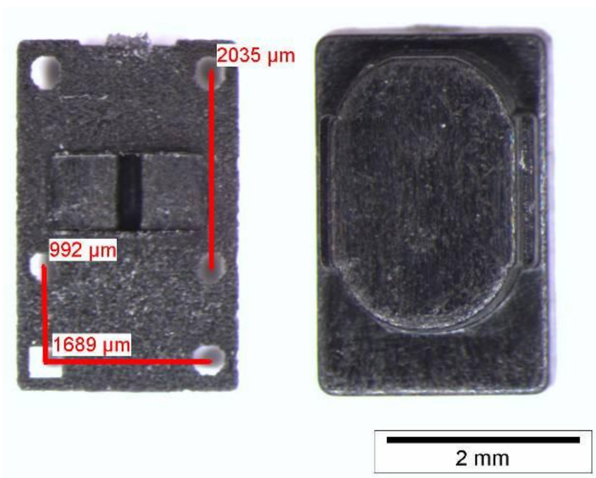

Figure 6: Top and bottom cap of the package after being micro molded at NTM

Figure 6 shows the outcome of the micro molding. Despite the ultra small feature sizes, all features have been transferred perfectly into Stanyl ForTii. Process setup is easy and fast and no flashing occurs with Stanyl ForTii.

Stanyl ForTii

The thermoplastic materials for micro molding also should be carefully selected to fit the process and required part design. Here the brand new high temperature polyamide Stanyl ForTii was selected for its good combination of thermal, mechanical and rheological properties. Parts of this material can withstand lead-free soldering conditions without degradation. Therefore the material is suitable for manufacturing miniaturized, small footprint SMT components. Stanyl ForTii is currently the only available high temperature polyamide enabling such a high flexibility in design and full compliance to lead free reflow SMT assembly. Stanyl ForTii furthermore is entirely halogen free, fully meeting OEM specifications.

With Stanyl (polyamide 46), Stanyl ForTii (polyamide 4T) and Xantar (PC/ABS) DSM Engineering Plastics is offering the broadest available portfolio of LDS grades and covers the entire temperature range in Electronics applications. A global presence of DSM Engineering Plastics, a presence since more than 20 years in the Electronics industry as well as a high application and design support level makes DSM Engineering Plastics a strong partner to OEMs and connector and component manufacturer.

LDS to selectively create tracks on thermoplastic parts

Molded parts with integrated tracks are called MID's (Molded Interconnected Devices). There are several technologies available to create MID's. Laser Direct Structuring (LDS) is the technology with the most design freedom to selectively plate plastic parts. The process to create a MID with LDS technology consists of three basic steps: molding of the thermoplastic part, selective laser ablation of the track-layout on the part and plating of the track layout.

Plastic parts of all shapes and materials fulfilling all kinds of functions are daily practice. Examples are housing parts of household appliances, mobile phones, interior parts of cars and even lunch boxes. A common and widely available process to manufacture plastics parts is injection molding. This process allows a lot of design freedom to come to 3D design solutions. This can also be translated in miniaturization. In order to do so, tooling and molding machines need to be adapted to the situation. Additional design rules should be considered. Not every molder has the capability for micro molding. The parts used in this study are molded in Nano Technology Manufacturing; they are specialized in ultra-precision- manufacturing.

After molding, the next step is laser ablation. During the selective laser ablation, the track pattern is written in the surface top layer of the plastic parts. The LDS additive in modified polymer is transformed into micro metal cores they appear on the surface of the tracks and are fixed in the polymer matrix. This allows electroless Cu plating of the tracks.

Design solutions

The design in our study demonstrates several design solutions. Between two parts a spool around a ferrite core is created, contact or soldering pads are created with only one sided lasering and mechanical fixation between the cover and base part is created.

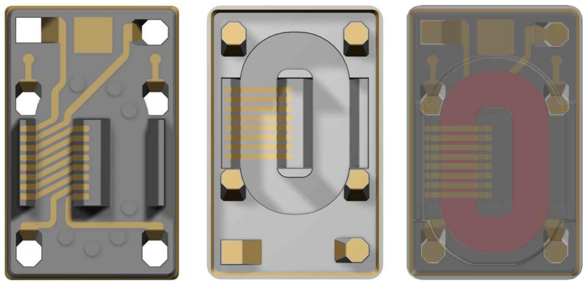

Figure 7: Top and bottom view schematics of the package as well as position of the ferrite

Compared to stitching, the windings of the spool can be more close to the ferrite core. There is no need to compensate the design for the use of stitching the wires. Hindering of the stitching head does not occur is simply no hindering. Apart form the used spool design in this study other design solutions are possible.

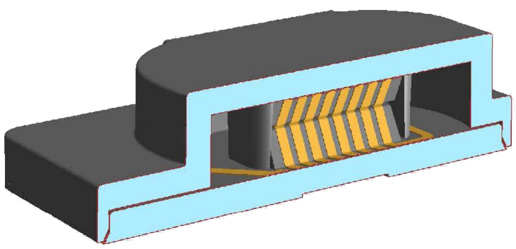

Figure 8: Assembly of top and bottom part closes the Cu tracks around the magnet and puts together both parts of the EMI filter

For ease of manufacturing it is chosen to use only one sided laser structuring to create the 3D track. Of coarse multi sided laser structuring is also possible. This allows even greater design freedom to create additional functions.

The solder pads for mounting on the PCB are part of the cover design. Due to through contacting of the legs of the cover and the tracks in the receiving holes interconnection with the tracks on the base is established. It demonstrates interconnection between tracks on 3D surfaces of different parts. In this way stacks of layers and via's are easily created. Again, only with one sided laser structuring.

Apart from fixation of the assembly on the PCB the cover and base should also be mechanically fixated. In micro-molded parts the standard snap fit solutions in plastics is not possible. There is no design space available leading to any mechanical strength. The demonstrated solution is a track, isolated from the electronic circuit, all around the inside of the cover and outside of the base. The soldering seals the parts into one assembly.

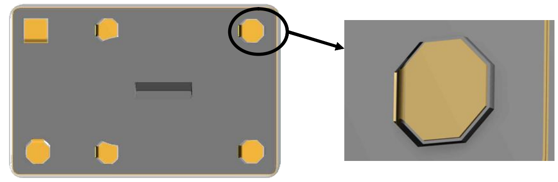

Figure 9: Realization of the solder pads by LDS

The last step in LDS process is the plating of the tracks. Due to the laser exposure the LDS additive in the polymer is changed into Cu-cores. Those metal cores are sensitive for electroless plating. For this plating, 15 µm standard commercial chemical processes are available, like MacDermid bath and Rohm &Haas. Once the tracks are covered with Cu additional layers can be added by galvanic plating.

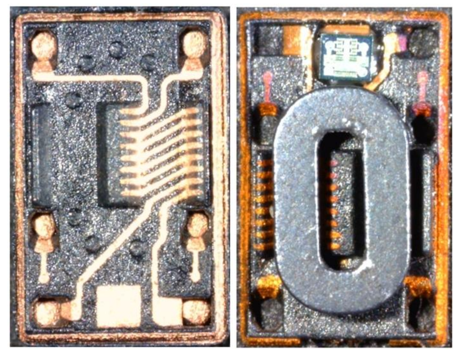

Figure 10: Optical microscopy of the two assembled LDS parts including the Semiconductor chip and magnetic coil

Stanyl ForTii

Stanyl ForTii is the very first entirely new high temperature thermoplastic introduced by any Chemical company in this millennium. Stanyl ForTii is a polyamide 4T, which DSM is marketing under the Stanyl brand family and which enlarges the DSM portfolio into the ultra high performance polymers best suitable for lead free reflow soldering applications. Stanyl ForTii is entirely halogen free meeting latest industry requirements.

Stanyl ForTii is an ultra high performance polymer meeting the highest requirements of lead free reflow soldering with a unique balance of thermal, mechanical and electrical properties. Stanyl ForTii is most suitable for demanding applications in the electronics industry/lighting/automotive/aerospace. In this project, we have selected this material due to its best fit to the required properties. In addition to the regular high performance requirements demanded by lead-free reflow soldering, the integration of components inside the package do require an excellent co-planarity of the package in order to avoid possible delamination of the chip from the polymer. Stanyl ForTii with its very high stiffness at reflow temperatures does enable this.

Conclusions

In summary, we have successfully shown the integration of Semiconductor ICs and Magnets in one thermoplastic package. LDS and micro molding technologies have enabled aggressive space reduction which can be used by OEMs to add additional functionality onto their PCBs or to simply reduce PCB size. Furthermore, OEMs can omit standalone components and hence also reduce component count which directly reduced their assembly cost.

The availability of an ultrahigh performance thermoplastic such as Stanyl ForTii from DSM Engineering Plastics has opened the door to realize LDS concepts on 3D designs in air cavity packages with high toughness, high co-planarity and excellent fit to lead free reflow soldering temperatures fulfilling JEDEC MSL 1 standard. The ease of processing of Stanyl ForTii enables an excellent material fit to the stringent requirements of micro molding.

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