Micro Injection Moulded MEMS with Integrated Piezoelectric PVDF

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Summary: Silicon micro technologies are established as manufacturing processes for micro systems. However, disadvantages of these technologies are restrictions in material choice as well as partially high manufacturing costs. Here an alternative technology for the production of micro systems based on “Multi Component Micro Injection Moulding” is presented. The potential of this technology is emphasized by describing an acceleration sensor with embedded piezoelectric sensor material. In detail, an overview of the technology, used materials, their functionalisation and smart systems integration is given for the use as structural health monitoring system in fibre reinforced thermoplastic components.

Keywords: Injection, Microstructure, Piezoelectric, Sensor.

1. Introduction

A recent trend in the development of innovative products for the aerospace [1] and the automotive sector, the consumer electronics as well as plant and equipment engineering is the use of new lightweight materials with additional sensory functions. This development means that more and more "intelligent" components are used. Current systems are a hybrid combination of component and sensor unit, as shown by the example of a shaft seal with integrated sensors [2].

In order to increase the functional density of lightweight components, sensor materials must be placed directly on or into the structure. In this paper, possibilities for integration of piezoelectric sensor materials in polymer-based lightweight parts are presented. With these load indicating layers, it is e.g. possible to detect mechanical strains in various structural configurations. Such an arrangement is being developed within the Competence Network for Nano Systems Integration [3]. The sensor system records dynamic mechanical loads which are generated by the piezoelectric effect via electrical charges originating from the piezoelectric polymer. After transforming these charges into a visual indication, they reduce the intrinsic fluorescence of the Quantum Dots which are located in this layer. At very high mechanical stresses no photoluminescence is detected once the stress limit of the structure is reached. This development is a key step towards the production of new kinds of functional components with fully integrated autarkic sensors.

An alternative to large-area sensors is the fabrication of polymer-based micro-electro-mechanical sensors that can be manufactured by micro injection molding and adapted to any component geometry. An example for this investigation is the development of polymer-based acceleration sensors.

The polymer-based sensors offer a wide range of applications with the following additional advantages: It is possible to produce large-scale sensor layers at low cost which can be applied to almost any surface geometry on the one hand as well as to manufacture such sensors by micro-injection molding in large quantities on the other hand. Further doors are opened to new possibilities for system integration, such as injection molding application/integration of sensors or actuators on or in plastic structures [4], such as housing. In addition, the technology is characterized by a broad choice of materials that allows embedding of the latest composite materials, such as optical quantum dots layers.

2. Experimental techniques and materials

There are several configurations to combine (micro-) injection molding technologies with technologies for the integration of piezoelectric polymers. Two variants should be made: First, the back injection of piezoelectric polymer films and second, the application of piezoelectric layers in or on injection molded components. Both methods are multifunctional applicable. A selection is dependent on the specific application. Both ways as well as the functional materials are object of the investigation.

2.1. Piezoelectric materials for the multi component (MC) micro injection molding technology

From the variety of so-called "smart" sensor materials such as piezoelectric polymers (ferroelectrics [5] and ferroelectrets [6]) and polymer-ceramics, polyvinylidene fluoride (PVDF) and Triflouroethylen (P(VDF-TrFE))-based composites were selected for the investigations [7]. This is due to the availability of materials, to the understanding of manufacturing processes, and to the appropriateness of piezoelectric properties [8]. In addition, these polymers are adapted to the passive parts of the polymer micro-systems with regard to the expansion coefficient and elastic characteristics of the materials.

The P(VDF-TrFE) films used in these experiments were prepared as previously cast films with a thickness of 20 microns. Wherein the required crystallinity, which is important for the piezoelectric properties, has been impressed by typical thermal aging. Depending on the experiment, the films were electrically polarized either before or after integration into the component. Here, the hysteresis of the polarization of the electric field (as described e.g. in [8]) was measured.

2.2. MC micro injection molding technology

With the MC micro injection molding technology shaping of micro-systems in one manufacturing step is possible, which includes the forming of the component, the mechanical connection of the materials and the electrical contact as well as a possible encapsulation (see scheme in Figure 1).

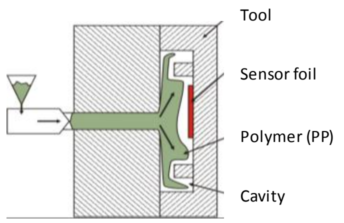

Figure 1. Schematic of back injection of piezoelectric polymers for the production of micro systems.

A critical point in the production of micro-systems is the process temperature in which a piezoelectric sensor layer is back-molded. With a typically injection temperature of about 270°C of the classical polymer polyamide 6 the melting temperature of piezoelectric polymers such as polyvinylidene fluoride is much lower (150 °C). This places new demands on the implementation of injection molding processes.

By means of appropriate tools and machine parameters (mold temperature, holding time and pressure) the necessary temperature for injection molding can be drastically reduced locally so that the piezoelectric sensor will get the temperature to bond together with the structure without losing their functionality.

2.3. Application of piezoelectric sensor foils on thermo-plastic components

In addition to the embedding technology of sensor films during injection molding, it is possible to apply piezoelectric sensor films subsequently on a thermoplastic component. This reduces the thermal stress of the sensor films. However, the production of the component in comparison with the back injection technology is not a one step process. For demonstration a passive part of an acceleration sensor made of polypropylene by micro injection molding and in connection with a piezoelectric sensor foil made by P(VDF-TrFE) was investigated.

3. Results

3.1. Back injection of a P(VDF-TrFE) foil

Back injection of piezoelectric polymer films was developed for the preparation of load indicative sensor layers. However, it is also useful for the processing of micro-electro-mechanical sensors.

The prepared test structure consisting of a polyamide 6 component and a piezoelectric functional layer between two electrodes, shown in Figure 2, and in this version includes an additional intermediate layer (HAF: heat activated film). In a second variant, the film was back injected directly behind. In both, a very good adhesion had been detected, and the intermediate layer further improves the adhesion.

Following the process of integration of sensor layers in injection molded parts is the polarization step. The polarization can also be done prior to injection molding. However, initial tests show a slight depolarization of the transducer material due to thermal stress.

During the polarization step an electric field consisting of bipolar and unipolar cycle of polarity is applied to the metalized transducer material [9]. Therefore, the measured current of polarity, as a function of voltage of polarity, shows very pronounced maxima (see Figure 2) and saturation at high voltages and no build-up of polarization during the unipolar cycles. Hence, it can be concluded to a very good polarization of the transducer, which had been integrated directly into the component before.

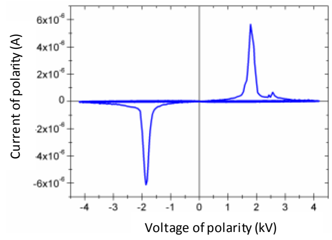

Figure 2. Curve of polarization of an integrated PVDF converter by micro injection molding.

3.2. Polymer-based micro electro mechanical acceleration sensor

In addition to providing a broad technological foundation, the system integration is the most important task in the design of new polymer based micro systems. Particularly important is the development of a design that must satisfy as many as possible prior to known requirements. With the help of various simulation tools micro systems will pre-calculated to obtain an understanding of the mode of action and to check for other influences of variations in geometry or material properties and operating conditions. Finally, measurement studies are needed to verify made statements and methods of the simulations.

To demonstrate the functionality of the new technology, a classic design of a spring-mass oscillator was used which is attached to a structure. This function integrated structure is shown in Figure 3. The inertial mass from the new polymer based sensor has the dimensions 3.17 mm x 3.17 mm x 1 mm, the length of the beam is 0.83 mm.

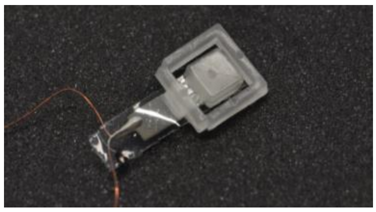

Figure 3. Developed polymer-based micro electro mechanical acceleration sensor.

For the charge generation in the layer of the transducer the so-called piezoelectric effect d31 is used, i. e. a mechanical deformation of the beam in bending.

The precalculation of the sensor is done with the finite element program ANSYS using realistic material law and loads.

As opposed to this, particularly Combined Simulations [10] are suitable to perform an optimization of such structures. The latter method is suitable for simulation of sensors as well as actuators [11].

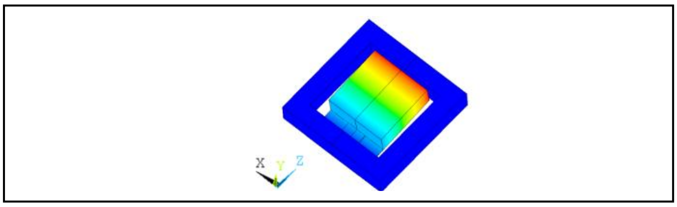

Figure 4. Deflection of the sensor with acceleration in the negative y-direction (red: deflection of 7,4 µm at 215 Hz).

Goal of the simulations was to investigate the optimal placement of the piezoelectric sensor on the injection-molded polypropylene film structure. The simulation model is shown in Figure 4. The calculations of the chosen design have shown a resonance frequency of the sensor at 215 Hz and a sensitivity of 4 mV/g in work direction. In addition, the frequency response of the sensor was calculated, which is shown in Figure 5.

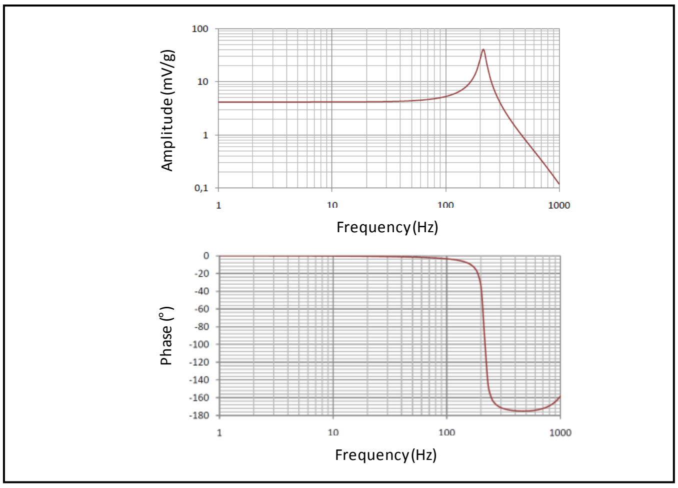

Figure 5. Amplitude and phase of the transfer function calculated with FEM.

For the characterization an evaluation circuit with a conventional charge amplifier has been used, the excitation was performed with a shaker. The applied acceleration was measured by means of a reference sensor. The resulting electrical voltage is linearly proportional to the acceleration, see Figure 6. The particular sensitivity is 0.55 mV/g and less than the value obtained in the simulation. In the processing of the sensor, the differences are largely due to geometric differences.

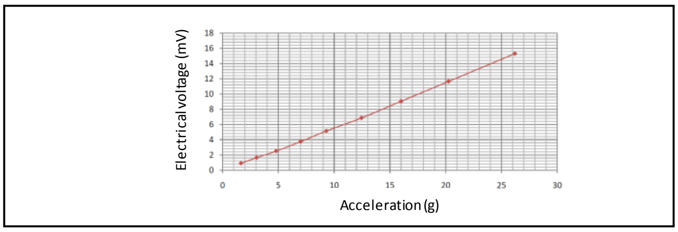

Figure 6. Electrical voltages as a function of acceleration at a frequency of 120 Hz.

4. Outlook

The results obtained show that the optimal setting for the characteristics of the new acceleration sensor even more detailed studies are needed, especially for the coupled mechanical-electrical behaviour, as well as the technological influences. Moreover, the process steps in detail and additional micro-systems and large-area sensors will be developed and optimized.

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