Design Concepts for Miniaturised Thermal Cyclers Based on Functional Additively Manufactured Multi-Material Components

The demands on components in terms of individualisation, functionalisation and miniaturisation, increased lifetime, but also resource efficiency during manufacturing and in use increase continuously. Additive Manufacturing (AM) technologies offer production possibilities that were previously unfeasible using conventional manufacturing technologies or required enormous effort. In order to demonstrate the future possibilities as a result of the extended functionalities of ceramic components, the development of a technology demonstrator took place in an interdisciplinary team.

Additively manufactured electrically insulating ceramic components with integrated electrical functionalities (e.g. sensors, actuators) represent an unprecedented disruptive innovation. Numerous research institutes and industrial companies have recognised this potential and are developing materials, processes, and equipment. A central challenge is the coordination of all aspects, as numerous questions regarding correlations between parameters and properties in the various process steps and especially with regard to the properties of the final component have not yet been fully clarified.

In order to realise the implementation of multi-material concepts faster and to make this potential usable for companies, Fraunhofer IKTS is already realising innovative multi-material components through targeted material selection and combination of various established as well as innovative shaping technologies.

Keywords
additive manufacturing, CerAMfacturing, functionalization, design, marketing, demonstrator

By using established, commercially available materials for the manufacture of highly complex geometries by means of Additive Manufacturing (AM) as well as functionalisation by means of screen printing, functionalised multi-material components can be produced within a very short time. These combine all the advantages of ceramic materials such as chemical and thermal resistance, high hardness, low density, biological properties, etc. with additional sensor or actuator functions. The high level of application maturity was demonstrated in a transfer project through the focused development of a user-centered demonstrator.

For this purpose, a focused format was developed and tested together with the Chair of Technical Design at Dresden University of Technology, the Chair of Marketing at Dresden University of Applied Sciences and the Leibniz Institute for Polymer Research – the Material Demo Lab. The aim of the 5-month format was to bridge the gap between research development and market application more quickly. The Material Demo Lab (MDL), which was devel-

Lars Rebenklau, Uwe Scheithauer,
Martin Kunath, Johannes Drechsel
Fraunhofer Institute for Ceramic Technologies and Systems – IKTS
01277 Dresden
Germany

Jasmin Schöne, Florian Sägebrecht,
Peter Schmiedgen
University of Applied Sciences (Fachhochschule Dresden – FHD)
Chair of Business Administration
esp. Marketing & Event Management
01069 Dresden
Germany

Anne-Katrin Leopold,
Stefan Schwurack
Leibniz-Institute of Polymer Materials Dresden
Processing Technology Department
01069 Dresden
Germany

Lenard Opeskin, Jens Krzywinski
Technical University Dresden
Chair of Industrial Design Engineering
01062 Dresden
Germany

Corresponding author: U. Scheithauer
E-mail:
Uwe.Scheithauer@ikts.fraunhofer.de

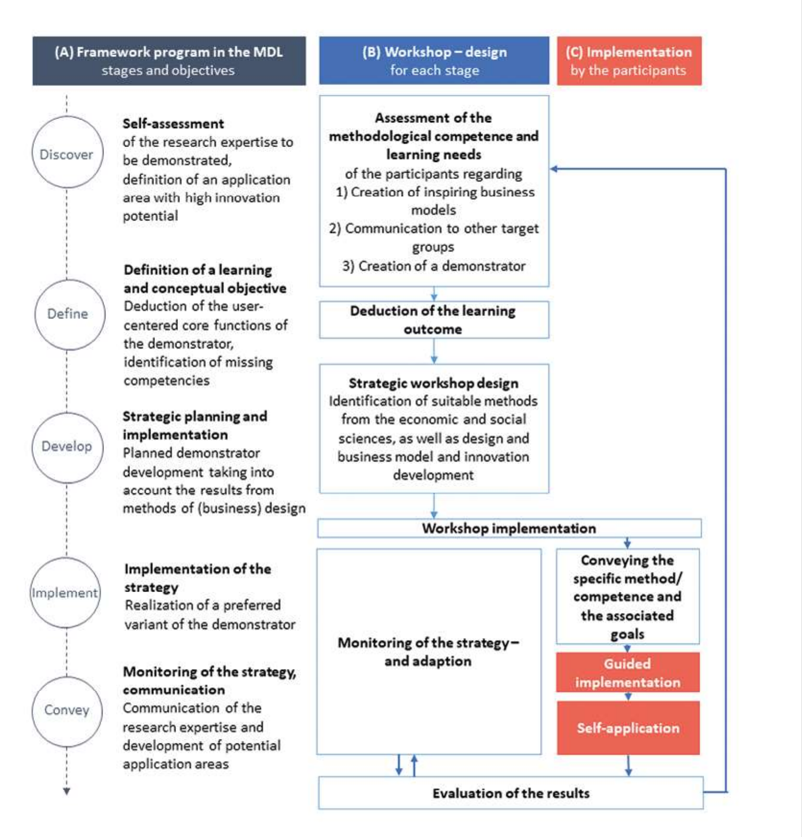

Fig. 1
Concept of the Material Demo Lab

Fig. 2
Design of the cooling (blue) and heating (orange) elements

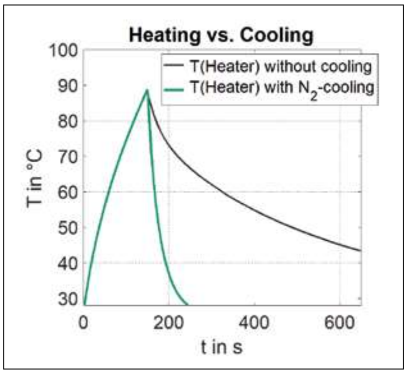

Fig. 3
Heating and cooling behaviours of the component without and with active cooling

oped as part of a BMBF-funded project, develops concrete solutions to meet this challenge.

To this end, methods and instruments of technical design, innovation management and business model development are modularised and made available to researchers via face-to-face workshops and virtual formats in order to promote user-oriented development even at initial stages and low TRLs (European Commission, 2014). The materials scientists at Fraunhofer IKTS are using the skills of marketing, design and product manufacturing to drive the development of a technology demonstrator as a boundary object [1] for communication to partners from industry and academia. Fig. 1 (A) shows the five phases of the framework developed to support materials scientists using collaboration and creative methods. In addition to the phases, the respective objectives are also illustrated. The phases present themselves in the process as follows: Discover, Define, Develop, Implement, Convey, based on the breakdown in the Delft Design Guide [2].

In the first workshop – the Discover Step – existing projects of the participants were discussed and they were introduced to their research topics. This resulted in a spectrum of competencies from which a vision for the demonstrator was developed in the subsequent step, the system mapping. The aim was to further elaborate and complement the competencies and to identify overlaps. Possible fields of application were identified, with the participants drawing on their existing portfolio of possible applications and interested partners. The decision to further work on a functional component for the medical and analytical industry was the result of the first workshop.

The core component

Starting point is the concept for a functional component based on an additively manufactured ceramic substrate with integrated cooling channels that has been functionalised by applied heating elements (Fig. 2) [3, 4]. The component functions as a thermocycler and offers possible applications in process, medical and analytical technology. With the aid of the component, it was possible to carry out the heating and cooling phases significantly faster (Fig. 3). Use as a thermocycler was therefore the preferred option for the technical application to be demonstrated.

The technologies

The component was fabricated using additive manufacturing technologies especially suited for ceramic materials. The CerAM VPP technology (Vat Photo-Polymerisation; also known as LCM – Lithography-based Ceramic Manufacturing) makes use of the so-called digital light processing principle. For this purpose, Fraunhofer IKTS uses the CeraFab7500 and the CeraFab8500 systems from Lithoz GmbH/AT.

As in stereolithography, free radical polymerisation of the binder system takes place by means of light of a defined wavelength, causing the suspension to solidify. Via a DLP module, the suspension is selectively irradiated with blue light, whereby all areas to be cross-linked on a given plane are exposed at the same time. Hence, the

Fig. 4
Sintered CerAM VPP component with internal cooling channels

Fig. 5
Screen printing on tubular component

process reaches a high level of productivity compared to spot-wise irradiation using a laser beam. Achievable densities following conventional thermal treatment of the AM green bodies reach at least 99,4 % of the theoretically possible density for Al_2O_3.

Fig. 4 shows the final CerAM VPP component under a bright light source to illuminate the inner channel structures.

The functionalisation of these components is based on thick-film technology. This is a technology for developing printed circuit boards using ceramic materials and based on thick-film pastes which are applied to substrates by screen printing. The components are then fired at 850 °C in a subsequent temperature step. Main fields of application for thick film components are in areas with harsh environmental conditions. The key advantage is that a variety of the materials necessary to print on Al_2O_3 are already commercially available. Pastes for conductors, heaters and insulators can be used. After firing, the conductor materials can be contacted using additional methods such as soldering or bonding. This means that other components such as electronic parts or sensors can be assembled if necessary. The production of planar thick-film components by means of screen printing is established worldwide because it is cost-effective and easy to automate. Several smaller individual components can be produced simultaneously on a commercially available ceramic carrier plate. However, for many sensor or thermal applications, planar geometries are only suitable to a limited extent. This is because a rod, tube or 3D component geometry can often significantly improve system efficiency.

Fraunhofer IKTS is therefore working on materials and technologies that can also be used to functionalise tubular elements and even completely freely designable ceramic 3D-printed bodies. In recent years, IKTS has built up extensive expertise in tubular screen printing on components with diameters as small as 2 mm up to tube segments with diameters of 70 mm.

Tubular screen printing is particularly suitable for applications that require a greatly enlarged functional surface, such as heaters or sensors. In the case of heaters, a large heating surface must usually be realised in a very small space in order to minimise unwanted heat dissipation. At Fraunhofer IKTS, tubular screen printing has already been used to manufacture efficient continuous flow heaters for a wide range of materials, miniaturised satellite engine elements, and heating elements (Fig. 5).

In order to achieve the communication and impression goals of a demonstrator, knowledge about the framework conditions and the addressee of the presentation is particularly important. For this purpose, experiences from previous demonstrators and their presentation, as well as the reaction of the addressees were collected and evaluated in Workshop 2 – the Define Step. The addressees were described in a prototyping canvas with the help of a persona analysis.

In the third workshop, application scenarios were developed from the information collected. These were presented to the participants for discussion. The goal was to evaluate which application scenario best clarifies and conveys the communication goals developed. Based on the defined functionality, four application scenarios were taken into closer focus: options 1 and 2 focused on the use within a PCR test system (Figs. 6–7).

In the intended demonstrator, the use in a PCR test system was designed. Such a system forms the basis for the rapid propagation and analysis of genetic information, such as that used in PCR tests for the detection of SARS COVID-19 viruses. Current systems use active heating systems and passive cooling and are only suitable to be set up in specialised laboratories, which is why it currently takes 12–48 h before a reliable result is available. With the help of multi-material thermal cyclers the sequence of heating and cooling phases can be significantly accelerated. A distinction was made between a stationary application in the laboratory (Fig. 7) and an application as a mobile device (Fig. 6). Option 3 provided for use within Thermogravimetric

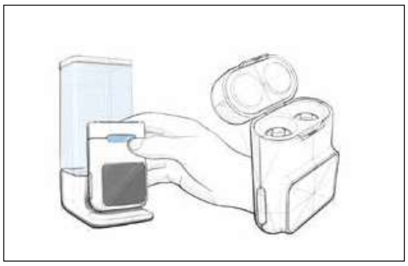

Fig. 6
Option 1: demonstrator for mobile PCR test system

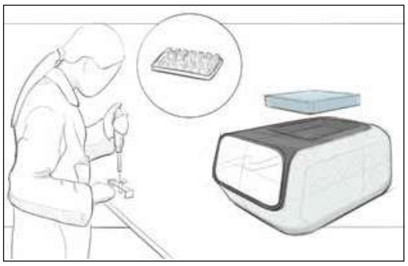

Fig. 7
Option 2: demonstrator for stationary application in a laboratory

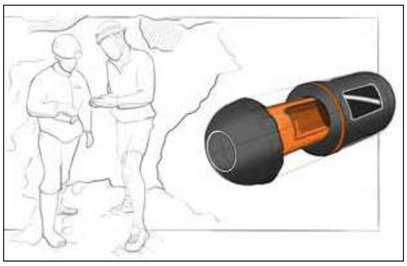

Fig. 8
Option 3: demonstrator for use in onsite Thermogravimetric Analysis (TGA)

Fig. 9
CAD model for option 1

Fig. 10
Exploded views of the CAD model in Fig. 9

Analysis (TGA) instruments (Fig. 8). TGA is an analytical method or method of thermal analysis that measures the change in mass of a sample as a function of temperature and time. Due to the high temperatures of up to 1500 °C required within the TGA, the participants decided not to pursue these options due to safety concerns.

Since physical experiences can play a decisive role at a trade fair, option 1 was selected and realised as a functional demonstrator. In addition to haptics and appearance, the focus was on simple operation and suitability for trade fairs. These design maxims were realised in a particularly flat handheld (Fig. 9), which made packaging a central problem statement. To functionalize the heaters, electronic switches (MOSFETs), which switch the heaters on or off as needed, had to be integrated in the "jetpack"-like central part of the structure (Fig. 10). The dedicated control algorithm is implemented on a powerful micro-controller on the rear inside of the package, which also outputs image data to the OLED front display. The target temperature is set via a mechanical toggle switch, as this conveys a valuable feel compared to the inflationary widespread touch screens.

Heating and cooling can be perceived in three ways:

1.) The digital heaters on the display show an animation that matches the current switching status, while the respective temperature in the physical heater is continuously read out and displayed.
2.) The lid, which is closed using a valuable magnetic lock, can be opened and the temperature can be felt by hand.
3.) Transparent tubes filled with temperature-sensitive colour can be inserted into the tubes to make the physical heating process visible.

In combination with a minimalistic stand (Fig. 11), this results in a vivid demonstrator with a technical-minimalistic look and a high-quality feel.

Fig. 11
Final fair demonstrator based on option 1

Summary

The cooperation of all participants not only resulted in the successful realisation of a very attractive demonstrator which could be successfully presented at the Productronica 2021 in Munich but was also a joyful experience and broadened everyone's horizons. A deepening of the cooperation is intended so that high-class technical developments can also be presented in a first-class manner in the future.

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