

# **Workshop on Advanced Polymer-Derived Ceramics**

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# Additive Manufacturing of Ceramics using Preceramic Polymers

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Preceramic polymers are precursors for ceramic phases of different composition. They convert into nano-structured ceramic materials in the system  $\text{Si(X)OCN}$  (with  $X = \text{Al, Ti, Zr, etc.}$ ), also called PDCs or Polymer-Derived-Ceramics, by high temperature pyrolysis. The resulting materials can have useful structural and functional properties.

This talk will discuss the fabrication of (mainly) porous structures starting from pure preceramic polymers (e.g. silicone resins) or silicone resins plus reactive fillers to produce advanced silicate ceramic phases, including bioceramics and Ceramic Matrix Composites, suitable for different potential applications.

Different types of additive 3D manufacturing techniques were employed, including: a) direct printing using a fused deposition printer (FDM); b) direct printing using an ink extrusion printer (DIW); c) indirect printing using a powder bed-based printer (BJ); d) indirect printing using a stereolithographic printer (DLP); e) indirect printing with sub-micron resolution using 2 Photon Polymerization fabrication (TPP).

Furthermore, we developed a novel hybrid approach to fabricate SiOC ceramic structures with feature sizes ranging from sub-micron to millimeter size, by combining 3D macro-stereolithography (DLP) with 2-Photon-Polymerization (TPP).

Finally, we are currently using silicone elastomers to fabricate simple shapes that can be further processed into complex architecture by post-printing folding and pyrolysis, as well as sacrificial fillers to generate components with multi-modal porosity.

Advantages and disadvantages of the different processing techniques employed, in relation to the use of preceramic polymers, will be discussed, and examples of produced and characterized porous structures for potential use in different applications will be presented.

## Resume of Paolo Colombo:

Paolo Colombo is a professor of Materials Science and Technology at the Department of Industrial Engineering, University of Padova, Padova, Italy. He graduated from the University of Padova with a degree in chemical engineering in 1985 and a diploma in Glass Engineering in 1988. He was an assistant professor at the University of Padova from 1990 to 1998 and then an associate professor at the University of Bologna, until 2005.

He is also an adjunct professor of Materials Science and Engineering at the Pennsylvania State University, a visiting professor in the Department of Mechanical Engineering of University College London, UK, a member of the World Academy of Ceramics, a member of the European Academy of Sciences and a member of the EPSRC Peer Review College (UK). He was a Foreign Scientist at INSA, Lyon, France in 2015, and a DGF Mercator Professor at the Technical University Bergakademie Freiberg, Germany in 2016.

He was elected Academician of the World Academy of Ceramics (2006), Academician of the European Academy of Sciences (2016), Fellow of the American Ceramic Society (2010), Fellow of the Institute of Materials, Minerals and Mining (2011), Fellow of the European Ceramic Society (2017). He was awarded a Fulbright Scholarship for the Pennsylvania State University in 1991, the Pfeil Award (The Institute of Materials, Minerals and Mining, London, UK) in 2007, the Global Star Award (The Engineering Ceramics Division of the American Ceramic Society) in 2010, the Edward C. Henry Award (The Electronics Division of The American Ceramic Society) in 2011, the Verulam Medal & Prize (The Institute of Materials, Minerals and Mining, London, UK) in 2013, the Global Ambassador Award (The American Ceramic Society) in 2016 and the Polish Ceramic Society Award in 2019.

He published more than 280 papers in peer-reviewed journals, 9 book chapters and holds 10 international patents.

h index Google Scholar (accessed 14/2/2021) = 63; Citations = 15382. h index Scopus (accessed 14/2/2021) = 54; Citations = 11152. h index WOS (accessed 14/2/2021) = 49; Citations = 9618.

He is co-editor of a book on cellular ceramics, a book on polymer-derived-ceramics and 11 proceedings books. He is the Editor-in-Chief of Open Ceramics (Elsevier, ISSN: 2666-5395) and is in the editorial board of 9 other international scientific journals

He has co-organized several international conferences, and has given numerous invited talks in the field of porous ceramics, polymer-derived-ceramics and additive manufacturing of ceramics. He was chair of the XVI conference of the European Ceramic Society (Turin, Italy, 16-20/6/2019).

Paolo Colombo's research interests include novel processing routes to porous glasses and ceramics (currently focusing mainly on Additive Manufacturing, using different technologies), the development of ceramic components from preceramic polymers and geopolymers, and the vitrification and reuse of hazardous industrial and natural waste.

# Advanced Polymer-Derived Ceramic Nanocomposites with Tailor-Made Structural and Functional Properties

Emanuel IONESCU

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Polymer-derived ceramics (PDCs) have been addressed in the last decades and were shown to possess intriguing properties which make them excellent candidates as structural and (multi)functional materials. PDCs can be synthesized via polymer-to-ceramic conversion of suitable single-source precursors, leading in a first step to amorphous single-phase materials, which subsequently undergo phase separation and crystallization processes to furnish bi- or multi-phase ceramic nanocomposites. In the present talk, the conversion of the single-source precursors into PDC, which are of amorphous nature, as well as subsequent phase separation and crystallization processes occurring at high temperatures will be addressed. Special emphasis will be set on describing the intimate relationship between the molecular architecture of the single-source precursors and the phase composition / microstructural features of the resulting PDCs. Preparative concepts for the knowledge-based design of PDCs with tailored phase compositions and property profiles as well as selected examples for structural and functional nanocomposite materials for energy-related and biomedical applications will be highlighted and discussed.

## Resume of Emanuel Ionescu:

Emanuel Ionescu, Heisenberg Research Fellow at the Department of Materials and Earth Sciences, TU Darmstadt.

Ionescu studied Chemistry and Physics at the University Bucharest and at Braunschweig University of Technology and received his PhD degree in Inorganic Chemistry in 2005 from the University of Bonn. In 2015, he finished his Habilitation at the Technical University of Darmstadt in the field of Ceramic Nanocomposites and received his *venia legendi*.

His scientific background and interests relate in general to (inorganic) materials synthesis and processing and in particular to the development of advanced ceramics with tailor-made chemical/phase compositions, morphologies, microstructures and property profiles for structural applications (construction materials, high-temperature resistant materials, materials for extreme, harsh environmental conditions) as well as for energy-related, environmental or biomedical applications.

Dr. Ionescu authored and co-authored more than 120 papers in peer-reviewed journals, more than 10 books and book chapters and three patents as well as gave more than 75 invited talks at domestic and international conferences and workshops. He is member of the American Ceramic Society, European Ceramic Society, German Ceramic Society, German Materials Society (DGM) and German Chemical Society (GdCh). Currently, he has been serving as Editor for the *Journal of the European Ceramic Society*, Associate Editor for *International Journal of Applied Ceramic*

*Technology and Materials Letter* as well as Secretary of the Rhein Ceramics Chapter Germany of the American Ceramic Society.