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Modern Polymeric Materials for Cold Plasma Generators

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Abstract

Disinfection and biodeactivation properties of atmospheric pressure cold plasma was already shown on bacteria and yeasts in the 90's. The most popular and safe type of cold plasma generators were found to be dielectric barrier discharges (DBD), where plasma is induced at a surface of dielectric materials covering high voltage electrodes. Such a feature allowed developers to test this technology at biological surfaces, even at a human skin. Our research focuses on the study and optimization of modern dielectric materials for designing more effective and safer new generation DBD generators. Tour target is miniaturization and elongation of lifetime of critical design parts, sustainability of operational parameters, minimization of manufacturing expenditures, repeatability of results and market potential. Recently, material PEEK was studied as potential candidate for replacing classical ceramic dielectric barriers. This polymeric material is characterized by good mechanical, thermal and electrical properties. Such properties allow us to reduce the size and the number of interfaces and spare parts within a plasma generator design in comparison with commercial ceramic-based approaches. PEEK is well machinable and printable by 3D printers.

Keywords: ceramic, DBD, discharge, PEEK, polymer

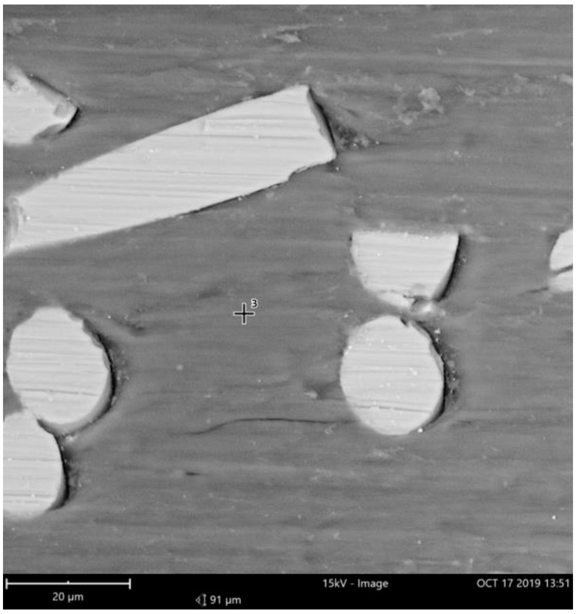
1. Introduction

The most popular and safe type of cold plasma generators were found to be dielectric barrier discharges (DBD), where plasma is induced at a surface of dielectric materials covering high voltage electrodes. Material PEEK was studied as potential candidate for replacing classical ceramic dielectric barriers. This polymeric material is characterized by good mechanical, thermal and electrical properties. Such properties allow us to reduce the size and the number of interfaces and spare parts within a plasma generator design in comparison with commercial ceramic-based approaches.

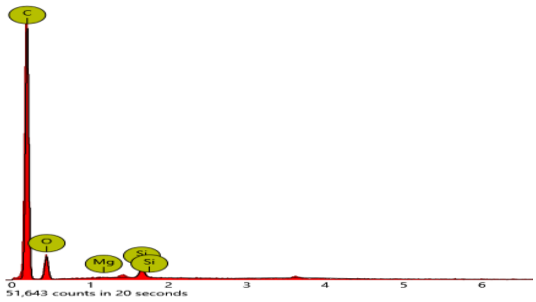
2. Polymer PEEK

Polyetheretherketone (PEEK) is an organic thermoplast having excellent mechanical properties. It is characterized by abrasion resistance and high chemical resistance. Furthermore, it also withstands hydrolysis and hot steam. The material is widely used, for example, in aerospace, nuclear, chemical and space industry, furthermore in health and food industries.

Figure 1: SEM analysis of PEEK+GF30 - spot 3 on the polymeric core - FOV: 91 µm, Mode: 15kV - Image, Detector: BSD Full

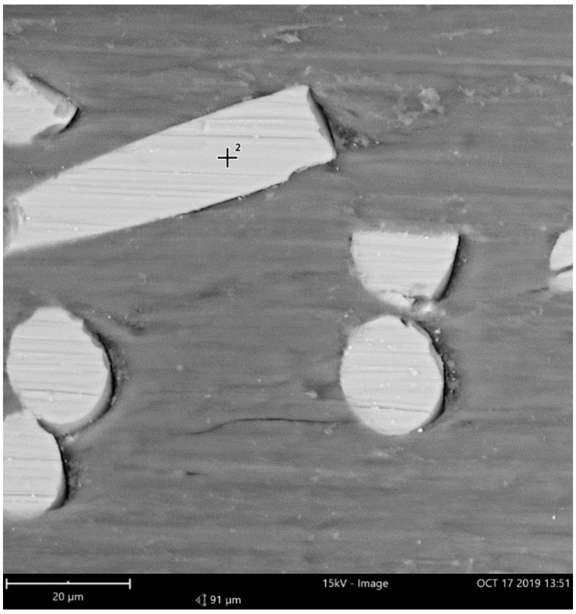


Element Symbol	**Atomic Conc.**	**Weight Conc.**	**Oxide Symbol**	**Stoich. wt Conc.**
C	82.69	77.88		
O	16.85	21.14		
Si	0.40	0.88	SiO_2	2.36
Mg	0.05	0.10	MgO	0.20

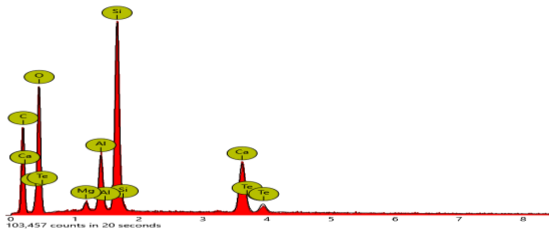


The basic PEEK composition is improved by admixtures of Teflon, carbon or glass fibers. These constituents affect its mechanical properties such as stiffness, creep resistance, friction coefficient and spatial stability. During the development of cold plasma device, we have put emphasis on PEEK of grade GF30 enhanced with glass fiber content. Figures 1-2 show SEM (scanning electron microscopy) images and results of elementary analysis of the polymer used in cold plasma generator having ring-to-ring electrode geometry. The mentioned glass fibers have detected by SEM, their diameter has been found approximately 15 µm. The material composition and concentration of the individual elements are listed in the tables in Fig 1-2. A comparison of cross-sectional structures for capillaries made of PEEK-GF30 and Al2O3 ceramics have also been carried out using SEM method (see Fig 3). As it is shown, no pores were observed neither in the GF30-, nor in the ceramic-based capillary.

Fig.2. SEM analysis of PEEK+GF30 - spot 2 on the filling particle - FOV: 91 µm, Mode: 15kV - Image, Detector: BSD Full



Element Symbol	Atomic Conc.	Weight Conc.	Oxide Symbol	Stoich. wt Conc.
C	50.58	37.93		
O	37.24	37.20		
Si	6.78	11.89	SiO_2	30.59
Ca	2.42	6.05	CaO	10.17
Al	2.22	3.74	Al_2O_3	8.51
Te	0.32	2.53	TeO_2	3.80
Mg	0.44	0.67	MgO	1.33



The operating temperature of GF30 is found within the range of -20 ° C to + 250 ° C and may be exposed to a temperature up to + 300 ° C for shorter time. Long-term exposure to the maximum operating temperature, for at least 5,000 hours, results in a decrease of 50% in its tensile strength. For thick-walled device components, only the top layer is affected by oxidation from high temperatures. The central part of the material remains unchanged.

Figure 3: Cross-sectional comparison of GF30 (left Fig) and Al2O3 (right fig.) capillaries

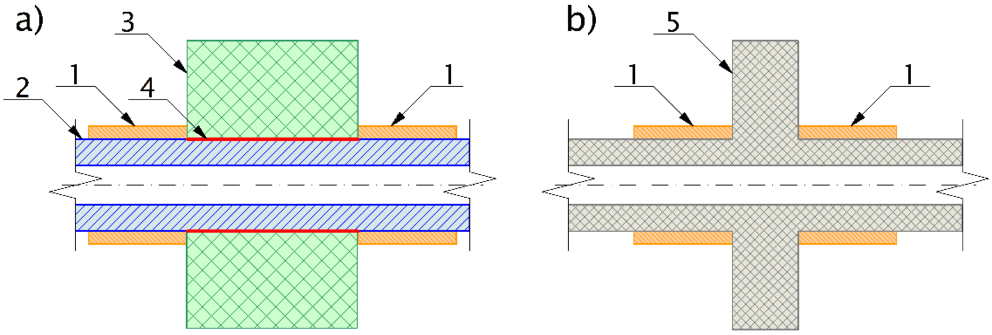
The dielectric strength of PEEK was found up to 24 kV/mm. For comparison, extruded Teflon has a dielectric strength 20kV/mm, an insulating Teflon reaches values up to 60kV/mm, while PTFE-GF25 glass fiber-filled Teflon only 13kV/mm. The relative primitivity of PEEK-GF30 is 3.2 at 1MHz and the specific electrical resistance is greater than $10^{14}\Omega$.cm. These properties predetermine the application of the material in electrical industry.

3. Machining properties of PEEK

Plastic materials of technical grads generally exhibit lower thermal conductivity and modulus of elasticity than metals. Heating can change the mechanical properties, dimensions and tolerances of device parts. High clamping pressure and blunt tools can also cause a deformation.

For machining it is recommended to use high-speed steel tools that must be sharp and clean. For glass-filled materials, carbide tools are recommended. During machining the produced chips should be removed to prevent damage of device parts.

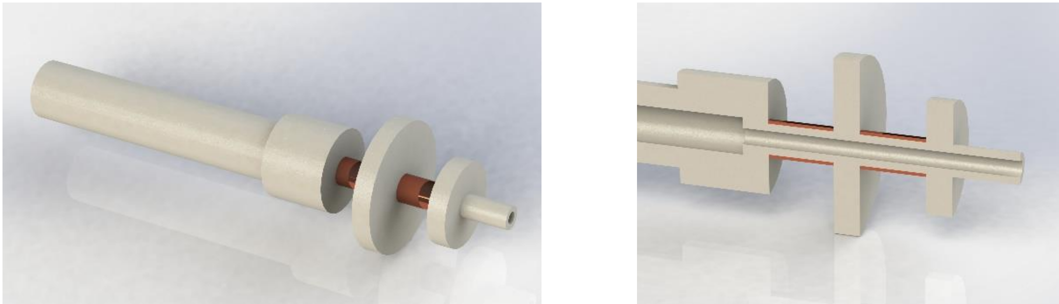
Figure 4: Side view of axially symmetric nozzles in a ring-to-ring electrode geometry of a DBD plasma generator with a) ceramic capillary, b) polymer capillary. (1: metal ring electrode; 2: ceramic capillary; 3: interelectrode barrier; 4: adhesive material; 5: polymer)



Cooling is generally not necessary for machining. Cooling is only necessary in case of drilling and cutting, to eliminate internal stress and ensure better surface quality. It is possible to use a cooling emulsion or compressed air, which also removes the chip from the cutting surface and prevents the tool from dulling. It is recommended to heat the part to 50 ° C before machining. It is advisable to select a low machining speed, since high speeds can cause material overheating.

Drilling is possible with high-speed drills. In case of deep holes, it is recommended to frequently pull out the drill bit to remove chips and prevent overheating. When drilling large diameters and it is recommended to drill gradually starting from a small predrilled hole to the desired diameter. When drilling modified material, it is advisable to preheat the material to 120 ° C.

Figure 5: Conceptual design of a nozzle prototype in a DBD-like cold plasma generator

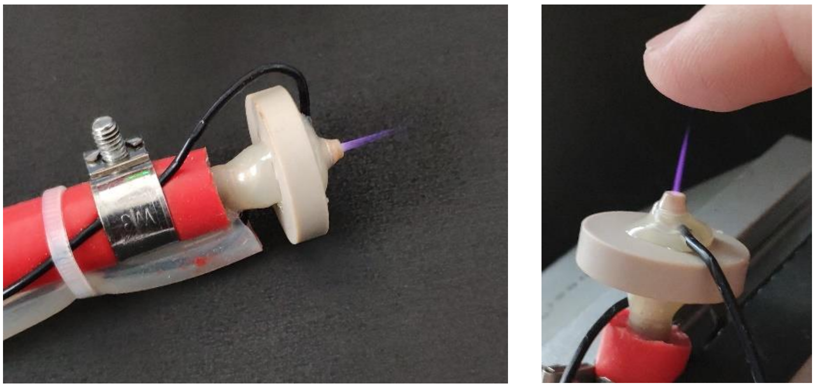


Preheating the modified polymer to 120 ° C improves cutting properties. A band saw or circular saw may be also used for cutting of rods and tubes. For cutting boards, a circular saw with a high feed rate is recommended. This prevents the blade from gripping and improves the removal of produced chips.

4. DBD plasma generator made of a polymer

Cold plasma generators are manufactured in different design and electrode geometries. Our research was focused on DBD (dielectric barrier discharge) plasma device having ring-to-ring electrode configurations. Figure Fig.4. shows a cross-sectional view of a plasma generating chamber in ceramic-based and polymer-based configuration. The dielectric barrier between active ring electrodes must be carefully designed to prevent spreading of surface discharges and streamer, that may cause termination of plasma generation and subsequent damage of the generator. Any air-like interface between materials must be filled with a suitable adhesive material. This solution is structurally demanding and requires several difficult steps for device assembly.

Figure 6: Working prototype of our DBD plasma generator having ring-to-ring electrode geometry



The use of PEEK-GF30 allows the plasma generator capillary and the inter-electrode barrier to be made in one piece as shown in Fig.4b. and Fig.5. Therefore, the electrode distances can be decreased to reduce the ignition and working voltage of the generator. However, it is necessary to maintain a minimum creepage to prevent surface discharging. A problem with the construction of a ceramic capillary-based plasma generator is also the design of protective barrier at the front electrode, the connection of the inlet gas hose to the capillary and its mechanical anchoring in the device. All these problems are solved by a polymer construction as shown in Fig. 5. The whole plasma generator can thus be made in one piece by standard rotary chip machining. Our working prototype made of PEEK-GF30 is shown in Fig. 6. and Fig.7

Figure 7: Testing our DBD-like cold plasma generator on biofilms.

5. Conclusion

The aim of this research was a material innovation against conventional solutions of DBD plasma generators. Our chosen polymeric material, PEEK-GF30 was studied from both electrical and machining point of view. The mechanical and electrical properties of this material bring structural advances, i.e. compactness of the generator design and ergonomics. The entire device can thus be designed in the form of a pen. The main output of our research is a device that is easy to manufacture. An important factor is the repeatability of production and the industrialization of such a design. Our next challenge will be the evaluation of effect of plasma on biomaterials and device manufacturing by 3D printing technologies.

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