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Short communication

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Preliminary characterization of glycerin, gelatin, propylene glycol, and cellulose based substrates for application in green microelectronics

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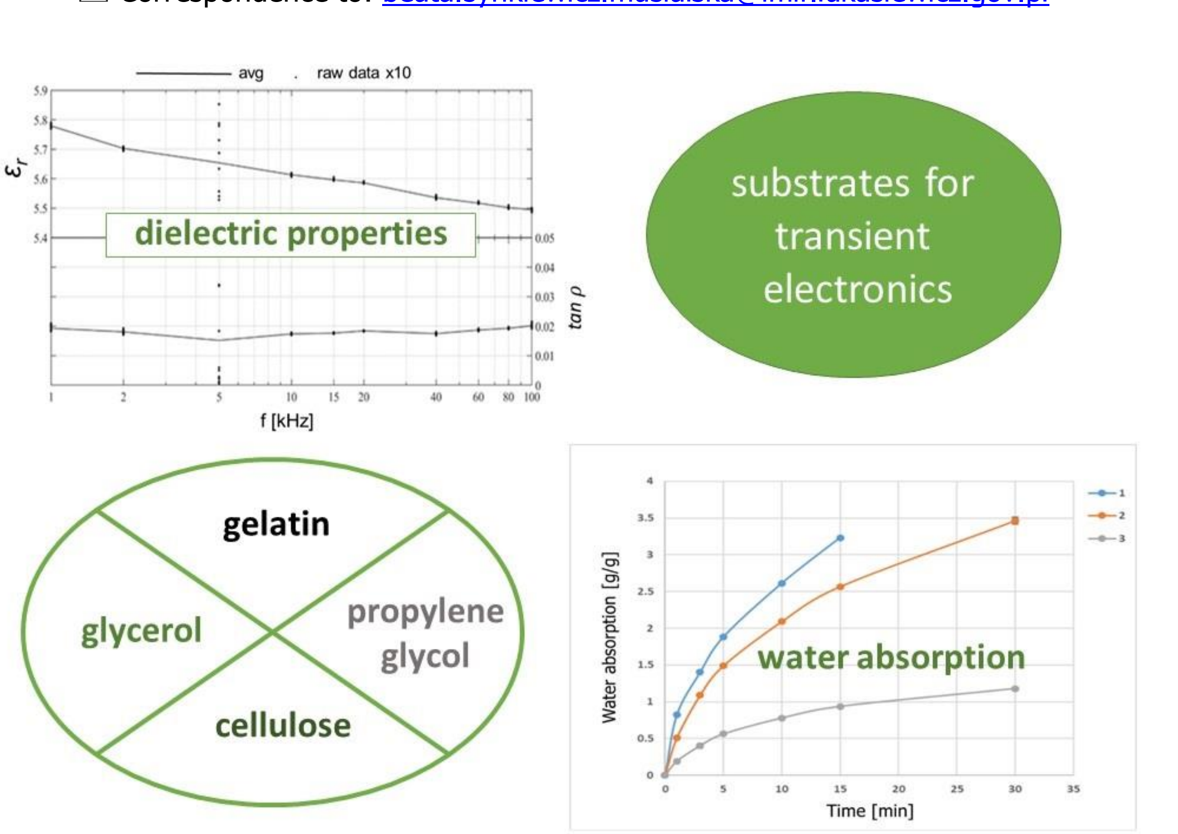

Abstract: In this study, the potential of biopolymer-based films for printed electronics was investigated. Three different tapes were prepared using a modified tape casting method, with compositions including glycerin, propylene glycol, and cellulose combined with gelatin. The films were evaluated for their temperature resistance, dielectric properties, and water absorption. The results indicated that the film with propylene glycol exhibited the highest temperature resistance, making it suitable for further application in electronic devices. Additionally, the dielectric properties were stable across the tested frequency range, and further research on biopolymer based biodegradable substrates is recommended for environmentally friendly electronics.

Keywords: Transient ICT, gelatin, printed electronics, flexible substrates

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Motivation and description of work

In modern-day information and communication technologies (ICT), there's an increasing trend of making significant changes by creating electronic hardware that is transient or time-variant. The most wanted are devices which perform their functions effectively throughout their use and still remain valuable or stay environmentally friendly after they are no longer usable. Organic materials of natural origin or their synthetic derivatives might present an inexpensive substitute for printed electronics and flexible devices [1]. The research strategy to achieve these goals involves development of new materials suitable for these applications. Biodegradable electronics exhibit substantial potential, particularly in the context of sustainable development and environmental preservation. Biopolymer films are significant in transient electronics applications and they find applications in various fields such as medical implants, packaging, environmental sensors and digital agriculture due to their properties such as biodegradability, biocompatibility, flexibility, mechanical strength and possible compatibility with electronics [2, 3, 4]. Based on the above motivation, it was decided to investigate the possibilities of implementing chosen biopolymer based films for printed electronics.

Materials

For the purpose of the research, three different tapes were prepared using modified tape casting method [5]. A prepared amount of solid substances was dissolved in an aqueous solution at a temperature between 60-90°C until a homogeneous consistency was achieved. The resulting mixture was then casted onto a silicone surface and dried at room temperature with air circulation for 24 hours. The slurries compositions were as described:

tape 1 (glycerin + gelatin in 4:6 weight ratio), tape 2 (propylene glycol + gelatin in 1:9 weight ratio), tape 3 (gelatin aqueous solution with 1% of cellulose and 1% of glycerin). The method for preparing the tapes was developed in the laboratory based on preliminary experiments to optimize the weight ratio.

Measurements

Transparent (1, 2) and milky white (3) films with a smooth surface and high tensile strength were obtained and tested for properties such as water absorption (the study involved weighing the samples before and after placing them in water at 5-minute intervals, then calculating the mass increase due to water absorption, expressed in grams relative to the initial mass), temperature resistance (size change after exposition to temperature range of 60 to 130°C) and dielectric properties (dielectric constant and dissipation factor were determined using a vector network analyzer E5061B ENA Vector Network Analyzer, in 1 - 100 kHz).

Results and Conclusions

Among the tested samples, the film containing propylene glycol additive (2) exhibited the best temperature resistance (Table 1). Exposure to a temperature of 90°C did not induce any shrinkage in the material, making it suitable for printing and drying of applied functional layers (with polymer based pastes). Reduction of dimensional changes at higher temperatures is possible by thermally pre-treating the substrate prior to the printing. Once the substrate is processed at a specific temperature and tension, only minor dimensional changes will occur in the following stages if the pre-treatment conditions are not exceeded [6]. Taking into account the results of the temperature resistance tests, the tape with polypropylene glycol has been selected for further analysis. Significant difference between shrinkage of samples with and without glycerol results from the melting point of this material (17.8 °C). Dielectric constant and dissipation factor of the substrates in the range of 1-100 kHz frequency are presented in Figure 1. Dielectric constant and dissipation factor of the material in the range of 1-100 kHz frequency are presented in Figure 1.

Table No. 1 Shrinkage ratio of prepared biopolymer based films

Shrinkage ratio (%) for a given temperature (60°C - 130°C)								
Sample	60°C	70°C	80°C	90°C	100°C	110°C	120°C	130°C
1 (glycerol+gelatin)	72%	72%	72%	72%	72%	78%	78%	78%
2 (propylene glycol+gelatin)	0%	0%	0%	0%	13%	13%	13%	13%
3 (gelatin+cellulose+glycerol)	25%	25%	25%	25%	36%	36%	36%	46%

Dielectric constant showed stable value from 5.495 up to 5.703 (decrease of the value with increase of frequency) and the average level of dissipation factor was 0.018. Comparing the dielectric constant values with other biodegradable substrate materials, we observe that these values are highly variable in similar frequency ranges (dielectric constant reaches a value below 10 for starch, while for methylcellulose it can reach up to 180 and is strongly temperature-dependent) [7]. Water absorption test (Fig. 2) showed the best results (the lowest level of water absorption) for the tape enriched with cellulose and glycerol. This examination confirmed that all 3 materials should be modified with additives to reduce their hydrophilicity, as continuous exposure to water can negatively affect the substrate quality.

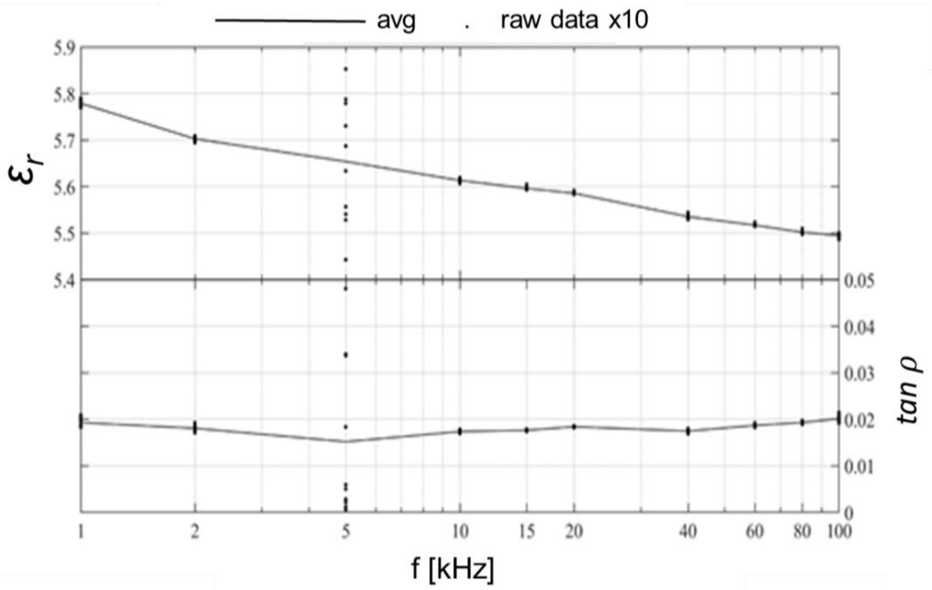

Figure 1. Dielectric properties of gelatin based tape enriched with propylene glycol

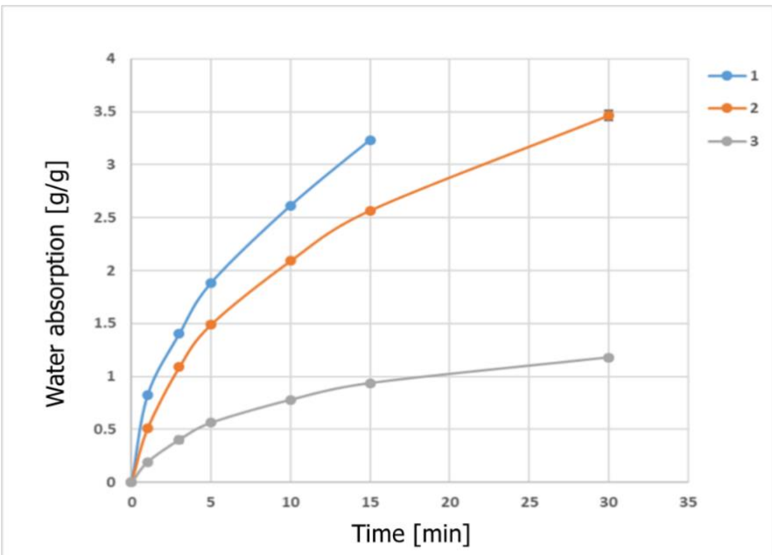

Figure 2. Water absorption of various gelatin based tapes (1-glycerol + gelatin, 2 – propylene glycol+gelatin, 3 – gelatin + cellulose + glycerol)

To maximize utility, the improvement of films or coatings can be achieved by incorporating different substances such as polysaccharides, lipids, and nanoclays, or through physical treatments [8]. Given that gelatin, cellulose and glycerol are biodegradable, this study shows potential for further research on those substrates in environmentally friendly electronic devices applications. Measurements of the dielectric properties of materials at a frequency of 2.5 GHz are planned to be conducted in the near future.

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