MSc Cezary Koneczny
PHD thesis

Properties of thin conductive layers created on composite textile structures with thermal vapor deposition

(Właściwości cienkich warstw przewodzących wytwarzanych na kompozytowych strukturach tekstylnych z wykorzystaniem metody termicznego naparowywania próżniowego.)

ABSTRACT:

Textronic, which is a synergic combination of electronics, information and knowledge of textiles, is classified to the areas of science and technology that can meet today's requirements for the production of specialized electronic systems. The textile product or the piece of that product can be the part of an electronic circuit or a flexible substrate for integrated active and passive elements.

The technologies of creation of thin metal layers on textile substrates are future-promising from the point of view of applications in textronic, flexible electronics, engineering materials, medical diagnosis and medical therapy. The thin conductive layers are the passive components of various kinds of electronic circuits which are used in electromagnetic shielding, anti-static protection as well as precise heating elements.

Creation and study of thin metallic layers properties on selected flexible substrates, also the textile ones, involves complex scientific problems, which are currently the scientifiv field of research in the various research centers (eg. J. Ziaja, 2013, Wroclaw University of Technology, M. Tokarska, 2015, Lodz University of Technology). It is impossible to achieve structure of submicrometer thicknesses with good electrical conductivity, in particular continuous conductivity over a large area, on any flexible substrate. It is one of the main problems to solve during the creation conductive paths on the textile substrates or the electrode sensors. The basic parameter determining the quality of the conductive layer is its resistance. There are significant metrological problems in this field, currently being considered (M. Tokarska, 2015, Lodz University of Technology).

In the author's opinion the technology of thin metallic layers on flexible substrates obtaining is an interesting area of research connecting such areas as materials science, flexible electronics, textronic and biomedical research.

There are many methods of creation of thin metal layers, including the sol - gel, chemical deposition - CVD, physical vapor deposition - PVD, pulsed laser deposition or magnetron sputtering. As the result of literature studying and my initial experimental work I undertook a study to obtain thin conductive layers with good electrical properties and durability acceptable for specific textronic applications. These layers are created on the surface of textile materials and composite textile structures, using physical deposition technologies - PVD. The possibility of the obtained conductive layers modification to optimize the specific properties of conduction will also be the aim of the research.

The purpose, theses and the range of the dissertation

On the basis of the preliminary results of author's research and literature studies the purpose and thesis of the dissertation were defined.

The main goal of the PhD dissertation was to investigate the possibility of thin conductive layers creating on various types of textile substrates and to investigate their properties by:

- define the necessary conditions for obtaining thin conductive layers which are characterized by high flexibility and low resistivity;
- investigate the effect of surface substrates modification on the obtained conductive layers properties;
- examine resistance of formed layers to external factors in the process of operation;
- determine the application properties of created layers.

The work consists of theoretical and experimental parts and it is divided into 7 chapters. The first chapter of the dissertation contains a preliminary discussion of the problems of conductive structure creation to the needs of the textronic systems. Chapter 2 of the work is dedicated to the textile materials characterization. The types and properties of textile raw materials and flat textile products are discussed, with particular emphasis on the textile composite materials.

Chapter 3 describes the characteristic of methods of thin conductive layers creation, including vacuum deposition - PVD (Physical Vapour Deposition) from resistance source and magnetron sputtering. Other methods of thin conductive layers creation, including CVD, digital printing etc. are also presented for comparison. The surface of the substrate or textile composite plays enormous role in the process of thin metallic layers producing. These problems were also discussed in this chapter. In the theoretical part the methods of surface resistance measurement (including two-electrode method, four-electrode method, Van der Pauw method) are presented.

Chapter 3 contains characteristics of thin conductive layers and methods of their measurement. The methods of the structure evaluation, the surface layers morphology assessment and measurement of the electrical properties of thin metallic layers are discussed. Particular attention was paid to the study of the properties of layers created on textile structures, measurements of other important physical parameters and structural studies (including optical microscopy and SEM). Chapter 4 presents the purpose and scope of the dissertation and the formulated PhD thesis.

Chapter 5 presents the results of research to the selection of textile and composites materials, the characteristics of the process of layer application and the basic physical properties of the resulting layers. It also includes the results for the determination of the surface free energy, roughness, surface morphology and the mechanical strength in tension and bending. The paper presents the results of studies on the effect of surface modification with the laser beam and plasma modification and its effect on the properties of obtained thin conductive layers. In chapter 6 the research on the production of textronic system components in deposited on the composite textile structures layers using micro-laser are discussed. Chapter 7 summarizes the results of the work.

The PhD dissertation concerned the creation of thin conductive (metallic) layers on textile materials. Technology, which was used by the author, was a method of thermal vacuum deposition. The conductive layers created on the textile structures are used in the design and

implementation of textronic system components. As a result of literature studies and experimental work author tried to create such layers on fabrics at the initial stage of the work. The results of these experiments were unsatisfactory because the electrical conductivity of the metallic layers occurred locally and strongly depended on even small deformation of the substrate (cloth).
Author suggested the idea of creating metallic layers on composite textiles, which have a spatial structure less developed and more stable than fabric. This idea was fully realized. Preparation of the conductive layer is important, but it is the first stage on the way to applying these solution in textronic as the conductor paths or electrodes. Masking technique, useful at the stage of examining the properties of layers, has proved to be insufficiently precise and inconvenient. The author was a co-developer of technology of using the laser ablation to form the elements of specified geometry and dimensions in created layers.

A variety of tasks was carried out during the research:

- dielectric properties of selected textile composites and the morphology of the surface were examined;
- the value of surface free energy were calculated;
- the process conditions for applying Ag, Au and Cu layers on a selected surface were developed and optimized by the experiment. The resistance value (resistance to the square), was taking into consideration as a fundamental criterion for assessing the quality of the PVD process.
- a laser and plasma surface modification composite substrates were done;
- the influence of elevated temperature, tensile and cyclic bending stresses on layers were tested;
- the possibility of laser forming of conductive elements in the layers formed on the composite textile substrates was examined.