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REGULAR ARTICLE

Developing Functional Fabrics with Nano-Metal Coatings for Multiple uses by Investigating their Electromagnetic and Ultraviolet Properties

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Functional fabrics including nano-metal coatings is an advanced application in textile technology that combines the distinctive characteristics of nanoparticles to improve fabric capabilities. These fabrics are meticulously designed to provide a wide range of uses, from protective textiles to high-performance athletics. Nano-metal coatings are added to the textiles to enhance their durability and conductivity. Moreover, examining their electromagnetic and ultraviolet (UV) characteristics indicates the possibility of providing protection against detrimental radiation and enhancing overall safety. This research aims to examine the nano-metal coated fabric materials containing Copper (Cu) and Silver (Ag) metals, that concentrates on their electromagnetic interference (EMI) and UV protecting characteristics. To achieve this objective, the thermal evaporation under vacuum technique has been employed to apply Cu and Ag coatings onto textile fabric samples. The assessment of the extent of coating on textiles is conducted by the utilization of Scanning Electron Microscopy (SEM) analysis. Both Ag and Cu coatings have been demonstrated to be beneficial for enhancing the EMI and UV protective characteristics of fabric-materials. Moreover, the implementation of Ag coating has been observed to be better in enhancing the EMI and UV protective capabilities of fabric-materials in the context of textile industries. This research depends on the thermal evaporation approach, which limits the investigation of other methods for coating.

Keywords: Copper (Cu) and Silver (Ag) metals, Nano-metal coatings, Fabric-materials, Electromagnetic interference (EMI) and ultraviolet (UV) protecting.

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1. INTRODUCTION

Functional fabrics with nano-metal coatings are a novel integration of materials science and textile technology [1], providing a wide range of possibilities in several industries. The integration of nanotechnology in textile manufacturing presents additional opportunities in terms of profitability [2], durability, and flexibility. In this scenario, the incorporation of nano-metal coatings has emerged as a pivotal advancement, resulting in a novel generation of flexible textiles with enhanced attributes [3].The application of nano-metal coatings, such as silver, gold, or copper, may impart different qualities to fabric by applying extremely thin layers of these metals [1]. Coating textiles at the nanoscale level results in exceptional properties, including improved conductivity, antimicrobial properties, and greater mechanical strength [4]. The materials exhibit superior characteristics in comparison to conventional textiles, enabling a diverse set of capabilities that are transforming various sectors, including healthcare and fashion.

The implementation of nano-metal coatings in textiles impacts their electromagnetic and UV properties [5]. These coatings are essential for protecting against EMI and providing efficient UV protection [6]. The importance of electromagnetic compatibility is growing in our developed world. Fabrics that are equipped with nano-metal coating function as a safeguard against detrimental electromagnetic waves, which have the capacity to interfere with technology or delicate machinery [7]. These textiles have significant potential to reduce the harmful effects of UV radiation emitted by the sun. Textiles with nano-metal coatings provide an

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innovative approach to address issues regarding skin health and the environmental consequences of UV exposure. The nano-metal particles function as a protective shield, obstructing the entry of detrimental UV radiation into the fabric and thereby safeguarding the skin [8]. This approach not only protects persons from the dangers of sunlight but also increases the lifespan of the cloth itself, as UV radiation is a recognized cause of material damage.

Fabrics with nano-metal coatings have a wide range of uses in several fields [9]. These fabrics are used in healthcare to create antimicrobial clothes for medical specialists, which help in implementing infection control measures. The electromagnetic shielding qualities of aerospace materials are highly beneficial for the production of electronic system components [10]. The fashion sector benefits from the aesthetic options provided by these upgraded materials, while nature lovers appreciate the improved UV protection for effective clothes. The incorporation of nano-metal coatings with functional fabrics signifies a revolutionary advancement in the field of material science [11]. The textiles that are produced a wide range of characteristics that effectively handle modern difficulties, such as dealing with electromagnetic interference and protecting against ultraviolet radiation exposure. These materials can transform the way we wear and also positively contribute to our health and technical progress.

This research aims to examine the qualities of textile fabric specimens coated with nano-sized Copper (Cu) and Silver (Ag) metals, in relation to their ability to protect against EMI and UV radiation. The subsequent portions of this study are divided into several categories. Section 2 provides the literature review conducted on the evaluation of fabrics with nano-metal coatings and their electromagnetic and ultraviolet preventions. The suggested research model is described in Section 3 of this research. The research outcomes are summarized in Section 4. Section 4 contains the conclusion of the research.

2. RELATED WORKS

Researchers of [12] established versatile coatings for fabrics in response to the growing need for materials that can protect against electromagnetic (EM) contamination. A composite coating was developed by combining "iron titanate (FT) and multiwalled carbon nanotubes (CNT)", resulting in an efficient shielding of both microwaves and UV radiations. The application of the coating significantly increased the electrical capacity of the material by a factor of 10.000, effectively filtered 99.9% of UV light that demonstrated the potential to enhance the market worth of cotton fabrics. The study [13] evaluated the "UV protection factor (UPF)" of cotton-polyester twill fabric that was treated with a "titanium-based metal-organic framework (MOFs) called NH2-MIL-125(Ti)", utilizing a method that involved synthesizing the MOFs directly on the fabric. Four criteria were utilized for the examination of inherent fabric properties. "SEM and dynamic light scattering (DLS)" techniques established the creation of MOF structures on the surface of fabric fibers. There were no significant disparities observed in the inherent characteristics of the coated and untreated fabrics.

The research [14] examined techniques for improving the UV shielding characteristics of textiles to provide protection against the detrimental impacts of UV radiation. The study encompassed traditional methodologies and examined the potential of nanoparticles in enhancing UV protection. The techniques involved the integration of UV blocking chemicals into the textile structure. The collected findings included information on advanced nanomaterial-based fabrics designed to protect against UV radiation, the fundamental processes responsible for their UV-blocking qualities, production methods, and factors to consider about the longevity of "UV-protective" fabrics infused with nanomaterials. Authors of [15] improved the quality of bleached cotton fabrics by utilizing both antibacterial and sun-protective characteristics by implementing the use of a blend of "natural bioactive substance (moringa leaf extract), titanium dioxide nanoparticles (TiO_2NP), and silver oxide nanoparticles (ZnONP). The findings demonstrated that fabrics infused with moringa extract, followed by TiO_2NP oxide powder, yielded the greatest number of beneficial findings.

3. METHODOLOGY

3.1 Fabric Components

The fabric-materials utilized in this investigation consist of cotton woven fabrics, and the material's physical features are discussed in this phase. The material was prepared by dividing into pieces of 12×12 cm. The fabric-material is a cloth made from "woven desizedgreige"materials. The fabrics-material consist of 94 % "combed cotton-fibers" and 6 % elasticated filament. Cottons consist primarily of a plant-based with a composition ranging from 89 % to 97 %. These fibers are characterized by the presence of long-chain cellulose molecules. The crystallinity of cotton fibers varies between 63 % and 73 %. Elastane fibers possess the ability to go through constant stretching of over 460 % and have a crystal structure level of 18 %.

3.2 Process and Components of the Coating

The fundamental concept of this technique is the vaporization of metal particles that were intentionally heated within a vacuum or inert atmosphere. Subsequently, the thermal evaporated nanoparticles are distributed in three dimensions onto the desired coating interface as mentioned in Figure 1. According to the coating procedure, the amount of vacuum is decreased to 1.10^{-7} Torr by eliminating or pumping to remove contaminants. A "tungsten basket" is used for the process of evaporated water, which is achieved by applying a high electric current among the electrodes to warm it. The basket contains metal fragments such as Ag, Al, Cu, In, or alloy coatings, which have less melting point than tungsten. That vessel incandesces due to low voltage and high electricity, causing the rapid evaporation of the metal content.

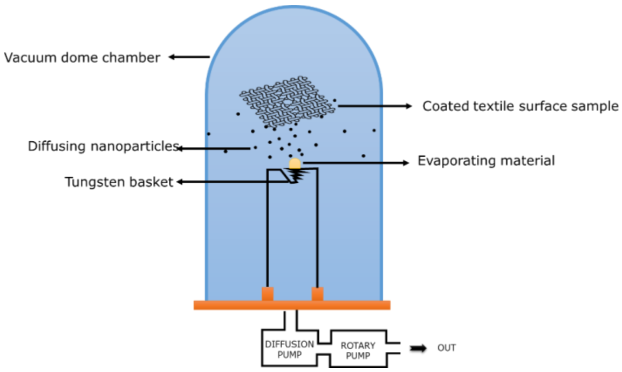

Fig. 1 – Physical vapor deposition (PVD) evaporator model

The metal is transformed into water vapor and spreads out in the cap, evenly spreading throughout the outer layer of the coating. Following deposition, a small amount of surface is created, wherein certain particles of metal infiltrate the cloth. The measurement of the thickness of coating is conducted through the utilization of atomic force microscopy. The investigation focuses on the UV protection characteristics, while disregarding the influence of width. The application of a protective layer on the surface results in a decrease in surface activity when exposed to an empty space, resulting in a cooling effect. The temperature during coating is maintained at room temperature, which is recorded using an infrared thermometer to ensure that the fabric is protected from direct heat exposure.

Theoretical calculations were used to determine the coating density ratios, which are presented in Table 1. According to the table, the weight of the Ag film coating is approximately three times greater than the weight of the Cu.The fabric samples were examined using the "FEI Quanta 650 Field Emission SEM" at magnifications of 100×, 1000×, and 5000× after the coating process. The "ELME MULTIMEG megohm-meter" was used to measure surface resistivity, which indicates conductance. The quantity of the coating substance was determined. The heat-evaporation approach secured the Cu/Ag particles, with no observed decreases. Abrasion testing was excluded due to the absence of any reduction in coating thickness.

Table 1 – Descriptions of coating

Coating materials	Ag	Cu
Coating distance	19 cm	19 cm
Mass of nanoparticles	39.34 mg	15.36 mg
Evaporated mass	1.4 g	0.6 g
Density of coated nanomaterial	3.18×10^4g/cm^2	1.55×10^4g/cm^2

3.3 Electromagnetic Reflection and Absorption Measurements of Fabrics

The "Agilent PNA-L VN microwave vector network analyzer with a single-horn antenna" was used to assess the reflection and transmission ratios, which are crucial for determining absorption properties. The use of both coated and uncoated instances, positioned in front of a metal plate, provided precise observations as mentioned in Figure 2. The transmission and absorption characteristics of the fabric sample were evaluated using the Cary 7000 optical measuring equipment, which operates in a wavelength range of 300 to 1100 nm. The evaluations were done on flexible materials of a constant size of 2 × 2 cm, obtained from heavily coated and uniform locations, during air circumstances.

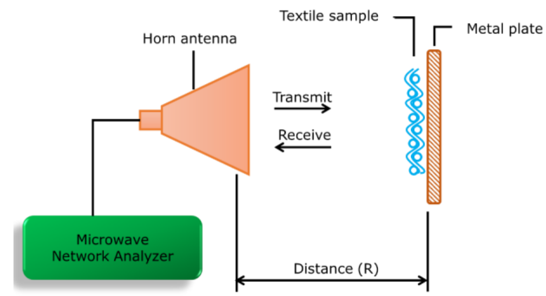

Fig. 2 – Electromagnetic absorption model

4. RESULTS

4.1 Evaluation of SEM Images

SEM examination demonstrates that the utilization of silveror copperas a layer of metal does not modify the woven patterns of fabric-materials. The presence of material coatings on the surfaces of fibers and threads allows for the formation of different interconnections among fibers. Untreated fibers, copper coated fibers, and silver copper coated fibers demonstrate apparent visual characteristics in SEM images. The copper materials once coated, take the shape of luminous nano-filaments, whilst the silver-coated materials emerge as smaller nano-platelets, eventually leading to the development of yarns with a matte coating. Although the coating level is low, a substantial absorption percentage is attained, indicating that increasing coating strengths might improve the efficacy of optical protection.

4.2 X-ray Diffraction (XRD) Examination

The XRD representations consistently demonstrate distinct peaks at 16°, 18°, 22°, 23°, 35°, and 40° (2θ angles) for the cotton fibers. The XRD analysis reveals different peak shapes at 2θ angles of about 35°, 40°, and 44° for the Ag/AgO nanoparticles, as illustrated in Fig. 3 (Violet mark-peaks of cotton and red mark-peaks of Ag/AgO). The XRD peaks for the Cu/Cu_xO_y sample are not visible in Figure 4. Due to their little large quantities and amorphous structure, Cu-nanoparticles are present on the outermost layer of the fabric. The XRD graphs show that the specimens had the maximum mass proportion of cotton, as well as comparatively small mass ratios of Ag/AgO and Cu/Cu_xO_y nanoparticles.

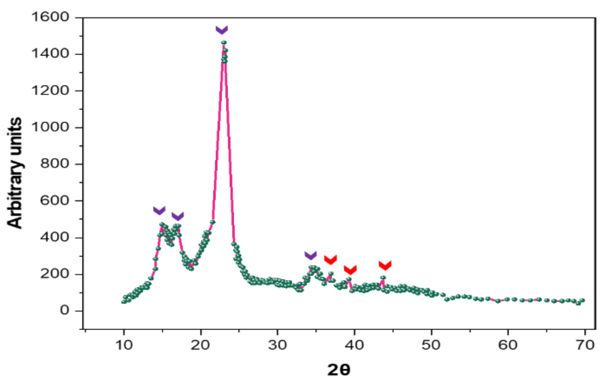

Fig. 3 – XRD graphics of Ag-coated fabric-material

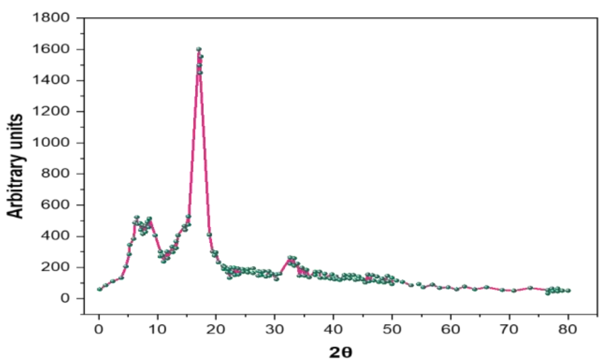

Fig. 4 – XRD graphics of Cu-coated fabric-material

4.3 Refection Examination

The reflection proportions of the samples coated with copper and silver were examined, and it is projected that the metallic surface would have a notably high reflection proportion. Both the Cu and Ag-coated fabric specimens have comparable properties to the metallic layer through various frequency ranges. The metallic appearance of the fabric corresponds to the uniform distribution of "Cu and Ag nanoparticles", as seen by the SEM images. Fabrics treated with nanoparticles of Cu and Ag demonstrate efficient performance as microwave filtering elements across a wide range of frequencies.

The EMI protection method entails the polarization of liberated electrons in the opposite direction to the electromagnetic field components of the incoming wave, so obstructing wave transmission. The suggested nanostructures exhibit a significant degree of uniformity in the "distribution of Cuand Ag nanoparticles" in relation to the wavelength of the incoming wave, thereby assuring efficient protection. Furthermore, the sparse distribution of "Cu and Ag nanoparticles" does not modify the fabric characteristics of the materials.

4.4 Examination of EMI Absorption

This research investigates the absorption characteristics of textiles coated with Ag and Cuby analyzing the observed reflection ratios (S11). Although metal surfaces generally exhibit accurate reflection qualities that prevent the absorption of microwave signals, the accurate detection of this occurrence is complicated by factors such as the measuring surroundings, antenna interruptions, and surface electricity. This research examines the direct reflection proportions of metallic surfaces and coated textiles, extracting their absorption properties in decibels (dB). The metal plate's reflections is represented by the metal (dB) values shown in Figure 5, while the reflection with the fabric with a coating is illustrated by the (Cu, Ag) coated textiles (dB) values. The absorption values quantify the discrepancy in reflections among the metal plate and the fabric coated metal plate.

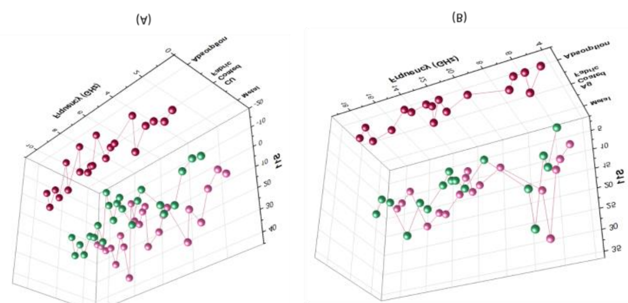

Fig. 5 – Absorption areas in coated fabric-material (A) Cu (B) Ag

The determined absolute reflective coefficients for both the metal surface and metal coated textiles usually greater than 10 dB within the frequency range of 5 to 18 GHz, which is in line with the expected outcomes. The coated textiles have superior absorption capabilities compared to metallic sheets, resulting in reduced absolute reflection ratios throughout the whole frequencies range. The Ag-coated fabric exhibits absorption ratios of 6.32 dB and 6.57 dB at frequency within 12.3 and 16.95, as demonstrated in Table 2.

Table 2 – Peak frequencies of reflection from Ag-coated fabric-material

Metal	GHz	Ag-coated fabrics	Absorption (%)	Attenuation
8.52	4.87	9.52	12.22	1.22
13.32	5.92	14.73	11.02	1.63
16.92	6.97	20.82	23.62	4.12
9.82	9.9	12.22	25.22	2.62
12.72	11.4	15.12	10.62	1.62
8.82	12.3	14.92	71.12	6.32
17.22	14.02	19.62	14.32	2.62
18.97	15.52	24.22	28.22	5.47
9.97	16.95	16.32	65.32	6.57
13.32	18.07	18.32	38.42	5.22

4 CONCLUSION

Functional fabrics with nano-metal coatings are evolving textiles by improving durability and conductivity. These innovative fabrics are used in clothing for protection and athletics. The investigation of their electromagnetic and UV characteristics reveals possible applications such as radiation protection. This research examined the nano-metal coated fabric materials containing Copper (Cu) and Silver (Ag) metals, that concentrated on their electromagnetic interference (EMI) and ultraviolet (UV) protecting characteristics. The thermal evaporation under vacuum technique was employed to apply Cu and Ag coatings onto textile fabric samples. The assessment of the extent of coating on textiles was conducted by the utilization of SEM analysis. Both Ag and Cu coatings demonstrated to be beneficial for enhancing the EMI and UV protective characteristics of fabric-materials. Moreover, the implementation of Ag coating has been observed to be better in enhancing the EMI and UV protective capabilities of fabric-materials in the context of textile industries. This was restricted to examining Cu and Ag coatings, potentially excluding additional nano-metal variants. Furthermore, the research depends on the thermal evaporation approach, which limits the investigation of other methods for coating. Future investigations will focus on developing scalable manufacturing techniques to facilitate the mass manufacture of textiles coated with nano-metal particles, examining the extended durability and capacity to withstand washing of these coatings would enhance their practical integration in many sectors.

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Розробка функціональних тканин з нанометалевими покриттями для багаторазового використання шляхом дослідження їх електромагнітних та ультрафіолетових властивостей

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Функціональні тканини, включно з нанометалевими покриттями, є передовим застосуванням у текстильній технології, яке поєднує відмінні характеристики наночастинок для покращення можливостей тканини. Тканини ретельно розроблені для забезпечення широкого спектру використання. Нанометалічні покриття додаються до текстилю для підвищення їх довговічності та провідності. Крім того, вивчення їх електромагнітних та ультрафіолетових (УФ) характеристик вказує на можливість забезпечення захисту від шкідливого випромінювання та підвищення загальної безпеки. Це дослідження має на меті вивчити тканинні матеріали з нанометалевим покриттям, що містять метали мідь (Cu) і срібло (Ag), зосереджені на їхніх характеристиках захисту від електромагнітних перешкод (EMI) і ультрафіолетового випромінювання. Для досягнення цієї мети було застосовано техніку термічного вакуумного випаровування для нанесення покриттів на зразки текстильної тканини. Оцінка ступеня покриття на текстильних виробах проводиться за допомогою скануючої електронної мікроскопії (SEM). Було продемонстровано, що покриття Ag і Cu є корисними для покращення захисних характеристик тканинних матеріалів від електромагнітних випромінювань та УФ. Спостерігалося, що використання Ag-покриття є кращим у покращенні EMI та УФ-захисних можливостей тканинних матеріалів у контексті текстильної промисловості. Це дослідження залежить від підходу термічного випаровування, яке обмежує дослідження інших методів нанесення покриттів.

Ключові слова: Мідь (Cu), Срібло (Ag), Нанометалічні покриття, Тканинні матеріали, Захист від електромагнітних перешкод (EMI) і ультрафіолету (УФ).