Design & Fabrication of MXene-Coated Fabric for EMI Shielding

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***Abstract*—Electromagnetic interference (EMI) pollution poses a huge risk to electronic equipment and human health and has become a new major source of pollution. Recent studies have shown that long term exposure of EMI can lead to harmful effects on human health, particularly for vulnerable groups such as pregnant women. The current work aims to investigate the use of MXene coated fabrics for EMI shielding, and in turn to provide an effective solution to protect the EMI effects affecting pregnant women is offered. The Shielding Effectiveness of the MXene coated fabrics with 20 dip cycles exhibited the highest shielding effectiveness with an average SE of 42 dB, and the fabric with 10 dip cycles showed an average SE of 33 dB while the fabric with 5 dip cycles exhibited an average SE of 20dB. The design of novel application fabric is prototyped for its working efficiency.**

Keywords—MXene-based shielding; EMI mitigation; Pregnancy safety; Electromagnetic pollution; Human-centric design

I. INTRODUCTION

Electromagnetic interference (EMI) has become a growing concern due to the widespread use of electronic devices and wireless communication systems, posing potential health risks, especially for vulnerable populations like pregnant women. Exposure to EMI can lead to adverse effects such as migraines, nausea, and even miscarriage [1]. Some common electronic devices that surround us like ovens, microwaves, television, mobiles, antenna towers which appear to have seemingly no effects emit powerful EMI waves ranging from 20 KHz to 100 GHz. It can subsequently interfere with the normal functioning of the human body, causing various health issues such as headaches, nausea, and miscarriage. This EMI causes various effects on pregnant women such as increased risk of miscarriage, congenital abnormalities, behavioural issues in children, (pregnancy loss before the 20th week of gestation, is considered a spontaneous abortion) and by the 20th gestational week, 12 to 15% of pregnancies have SM.

MXene, a two- dimensional material composed of layers of transition metal carbides or nitrides, has high electrical conductivity and excellent mechanical properties, making it a promising material for EMI shielding applications [8]. MXene offers high surface area, outstanding electrical conductivity, and ease of processing, making it an ideal material for EMI shielding applications. This reason mainly contributes to the growing research on MXene and its potential applications in the specific area of EMI shielding. Numerous studies have demonstrated the high EMI shielding effectiveness (SE) of MXene-based composites [2]. This project aims to create an MXene-based EMI-shielding fabric specifically for pregnant women, providing them with a secure environment and reducing the risk of EMI-related health problems [3].

MXene is a family of two-dimensional transition metal carbides or nitrides material which are knownfor their strong blocking of Electromagnetic interference [7]. This MXene has greater shielding abilities on EMI due to its strong electrical conductivity and high surface area. MXene's metallic-like conductivity due to its unique electronic structure, is crucial for effective EMI shielding by facilitating the absorption and reflection of electromagnetic waves [6]. The two-dimensional structure of MXene provides a large surface area, enabling efficient absorption and scattering of electromagnetic waves, leading to enhanced EMI shielding effectiveness. It also possesses few distinctive qualities like excellent mechanical properties, including high strength and flexibility, making it suitable for flexible and wearable applications and exceptional chemical stability which enabling its integration into various matrices and environments without significant degradation [4]. Since MXene can be converted intovarious forms such as films, coatings and composites, it results in increased EMI Shielding Effectiveness ranging from 31dB to 53dB [10-13]. Many studies explore the potential applications of $Ti_3C_2T_x$ coated fabric in avariety of disciplines, including aerospace, military,and consumer electronics [5]. They emphasize the fabric's benefits, such as its high conductivity, scalability and multifunctionality. To address the above mentioned issues, the development of effective EMI shielding materials is crucial, and MXene, a two-dimensional nanomaterial, has emerged as apromising candidate for EMI shielding, mainly the novelty apart from the fabric design for prototyping lies in the application towards human wear safety which includes maternity wear, industrial safety uniform in radiation prone areas.

II. LITERATURE REVIEW

The analysis of problems stated from literature and the proposed material characteristics is performed systematically. Risk of EMI waves on pregnant women: Pregnant women and fetuses are vulnerable to EMI radiation. This study aims to prove microwave radiation damages the placenta barrier. The radio frequency pregnant women tend to absorb daily has shown concerning interaction. Recent research indicates a link between cell phone use by pregnant women and an increased risk of miscarriage, congenital abnormalities, and behavioral issues in children. The most frequent early pregnancy problem is spontaneous miscarriage (SM). Miscarriage, or pregnancy loss before the 20th week of gestation, is considered a spontaneous abortion. By the 20th gestational week, 12 to 15% of pregnancies have SM. The large population-based studies found no correlation between living near power transmission lines and video display terminals and birth outcomes like preterm birth, low birth weight, small for gestational age birth, infant sex,

Spontaneous abortions or congenital anomalies. Studies focused on how MFs affected early pregnancy loss in some cases. Measurements of video display terminal MFs, however, showed that a woman's risk of miscarriage was more than three times higher when she was exposed to a video display terminal with a high MF level [9 milligauss (mG)] when pregnant [1].

MXene as a shielding tool: Due to their distinctive qualities, including high conductivity, outstanding mechanical strength, and exceptional chemical stability, MXenes, a family of two-dimensional (2D) materials, are quite popular in this niche of scientific domain. Due to these characteristics, MXenes are a strong contender for electromagnetic interference (EMI) shielding, among other uses. MXenes have a strong electrical conductivity and a huge surface area, which contributes to their superior EMI shielding abilities. MXenes have a high electrical conductivity, which enables them to efficiently absorb and reflect EM waves, and their huge surface area offers a lot of room for EM wave absorption [2].

Sustainability of EMI shielding fabric: The desire for wearable materials with multifunctional features like EMI shielding and passive radiation heating is covered in the first section of the article. The authors draw attention to the shortcomings of currently available wearable fabrics and the requirement for novel materials with enhanced qualities. This paper discusses the integration of silver nanowire into their fabric which is responsible primarily for the high EMI shielding. They achieved this technique by simply using a commercial fabric making it low cost and easily acquirable [3].

Integration of MXENE with fabric: Beginning with a discussion of the increasing demand for EMI shielding materials because of the growing use of electronic devices and the need to safeguard them from external electromagnetic interference, the paper then moves on to describe the characteristics of EMI shielding materials. The authors emphasize the limitations of extant EMI shielding materials and the necessity of developing new materials with enhanced properties. The scientific study explores potential $Ti_3C_2T_x$-coated fabric applications in various disciplines, including aerospace, military, and consumer electronics. Paper emphasizes the fabric's benefits, such as its high conductivity, scalability, and multifunctionality [4].

III. METHODOLOGY

Methodology or the process flow of $Ti_3C_2T_x$ coated fabrics is provided as in Fig. 1. From the synthesis of single layer MXene to formulation and preparation of coating using the solution is as per methodology or process flow defined, which is followed by testing and characterization.

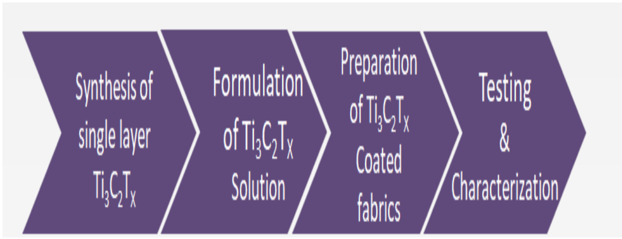
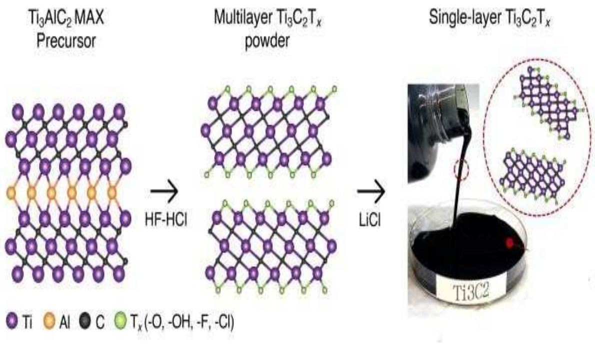


Fig. 1. Process flow of synthesis of MXene coated fabrics

Single-layer $Ti_3C_2T_x$ MXene was synthesized using a mixed acid method with the Al-rich $Ti_3C_2T_x$ MAX precursor. To the above, 3g of $Ti_3C_2T_x$ MAX powder (particle size<32 µm) was added to an etchant solution comprising 36 mL of 12 M hydrochloric acid (HCl, 37%), 18 mL of DI water, and 6 mL of 49% hydrofluoric acid (HF). The resulting mixture was stirred at 600 rpm for 24 hours at 35°C. After etching, the multilayer $Ti_3C_2T_x$ MXene was washed with DI water and centrifuged repeatedly at 3,500 rpm for 5 minutes until the pH reached 6-7. For delamination, the multilayer $Ti_3C_2T_x$ MXene was mixed with 3 g of lithium chloride (LiCl, 99.3%) and 50 mL of DI water, stirred at 600 rpm for 24 hours at 35 °C. The resulting solution was washed and centrifuged at 3,500 rpm for 5 minutes, with the clear supernatant decanted. This process was repeated three more times for 6 hours at 3,500 rpm until a dilute dark- greenish supernatant was observed, containing single-layer $Ti_3C_2T_x$ MXene along with unreacted MAX and multilayer MXene.

(a) (b)



(c)

Fig. 2: (a) Delamination of Multilayer Ti3C2Tx MXene using lithium chloride and DI water (b) Sediment containing unreacted MAX, multilayer, and single-layer Ti3C2Tx MXene (c) Schematic of Ti3C2Tx etching by HF-HCL mixed acid method, followed by delamination using aqueous LiCl solution

The sediment, composed of unreacted MAX, multilayer, and single-layer $Ti_3C_2T_x$ MXene, should be dispersed in DI water and centrifuged at 3,500 rpm for 20 minutes. The dilute dark-greenish supernatant should be collected, and the sediment discarded. The remaining supernatant, consisting of delaminated single - layer $Ti_3C_2T_x$ MXene, should be washed one more time by centrifugation at 9,000 rpm for 30 minutes until a clear supernatant is obtained. This process should be repeated until a clear supernatant is obtained. The sediment containing the single-layer $Ti_3C_2T_x$ flakes should be suspended in DI water after removing the clear supernatant.

First the fabric should be washed with a mild detergent and thoroughly rinsed with water to remove any impurities and dirt. The fabric should be dried completely before coating. The prepared fabric is dipped into the $Ti_3C_2T_x$ dispersion for a specific period, typically a few seconds to a minute, depending on the desired thickness of the coating. After dipping, the coated fabric is taken out of the dispersion and allowed to dry in air for a few minutes to remove excess solvent. This process is repeated until the desired MXene loading is achieved. The fabric is coated with different numbers of dip cycles, ranging from 5 to 20, to study the effect of coating thicknesson EMI shielding efficiency.

(a) (b)

Fig. 3. (a) Fabric is dipped into the Ti3C2Tx dispersion (b) MXene Coated fabric after air drying

The EMI shielding efficiency of the fabric was measured using Vector Network Analyzer (VNA) over a frequency range of 1 GHz to 18 GHz. The fabric was placed between two coaxial cables, and the VNA was used to measure the reflection and transmission coefficients of the fabric. The angle of incidence was controlled at zero degrees, and all measurements were taken in a shielded chamber to minimize external interference. After the initial testing, a washing test was conducted to evaluate the effect of washing on the EMI shielding efficiency of the fabric. The fabric was washed by hand using standard detergent and air dried. After washing, the fabric was retested using the sameVNA setup as before.

IV. RESULTS & DISCUSSION

The MXene-coated fabric is fabricated for prototype by dip-coating method with varying numbers of dip cycles, ranging from 5 to 20. The EMI shielding efficiencyof the fabrics is evaluated using a Vector Network Analyzer (VNA) over a frequency range of 1 GHz to 18 GHz., the durability of the fabrics isevaluated by washing tests and the structural characteristics of the MXene-coated fabrics is analyzed using X-ray diffraction and the finals results are obtained.

The VNA shows that the MXene-coated fabrics exhibiteater EMI shielding properties according to the number of dip cycles performed. The results showed that the MXene coated fabric, as in Fig. 4(a), with 20 dip cycles exhibited the highest shielding effectiveness with an average SE of 42 dB, and the fabric with 10dip cycles showed an average SE of 33 dB whilethe fabric with 5 dip cycles exhibited an average SEof 20dB. Thus, the VNA provides computable evidence of EM shielding performance by the MXene coated fabrics.

The results of the washing test show that the MXene-coated fabrics are highly durable and undergoes only minimal decrease in the shielding effectiveness even after consistent washing by hand with mild detergent and then drying it. The SE of the MXene-coated fabrics were decreased by less than 2dB, as in Fig. 4(b), which is highly negligible and has no impact on the effectiveness ofthe fabric. This shows that the MXene-coated fabrics are highly durable and can withstand washing and drying conditions.

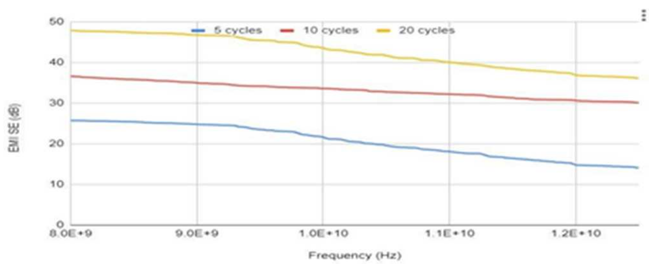


Fig. 4 (a) Comparison Graph of the EMI Shielding effectiveness between fabrics with no. of dip cycles

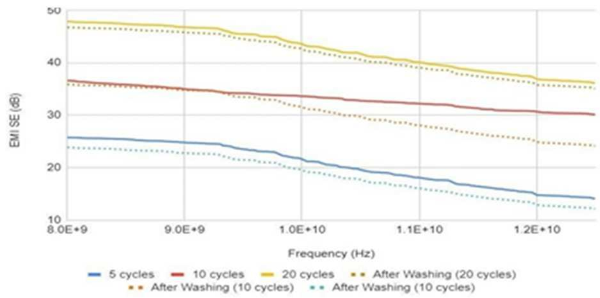


Fig. 4 (b) EMI Shielding Effectiveness before and after washing test

X-ray diffraction (XRD) analysis, as in Fig. 5, provided valuable insights into the structure of the MXene-coated fabrics, confirming the successfuldeposition of MXene on the fabric surface. Theintensity of the diffraction peaks increased with the number of dip cycles (Fig. 4), supporting the VNA results and indicating an increase in the crystallinity and thickness of the MXene coating. Overall, the study establishes MXene-coated fabrics as a promising and durable approach for effective EMI shielding applications across various industries.

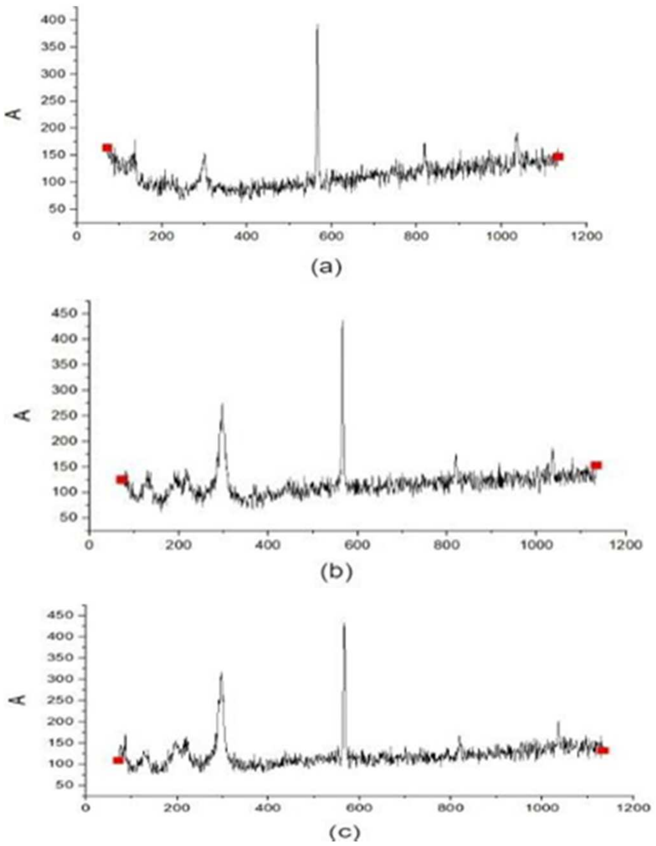


Fig. 5. XRD patterns of MXene coated fabric dipped (a) 5 cycles (b) 10 cycles (c) 20 cycle

The application of MXene-coated fabrics as a solution for electromagnetic interference (EMI) shielding demonstrates significant potential in delivering both efficient and long-lasting protection against electromagnetic radiation. These findings underscore the considerable promise of MXene-coated fabrics as a viable and durable option for EMI shielding in various practical applications. As a result, the EMI shielding effectiveness of theMxene-coated fabric is increased and it depends upon the number of dip cycles performed, the fabric is extremely durable and has less impact on decrease in SE after washing and the X-ray diffraction shows distinct diffraction peaks for the MXene-coated fabrics, indicating the successful formation of the MXene coating on the fabric surface.

V. CONCLUSION

The study's results highlight the remarkable shielding effectiveness of MXene-coated fabrics, which remains robust even after undergoing laundering processes. Moreover, the X-ray diffraction (XRD) analysis offers valuable insights into the structural aspects of the MXene-coated fabric, contributing to a deeper understanding of the underlying EMI shielding mechanism.

The Shielding Effectiveness of the MXene coated fabrics with 20 dip cycles exhibited the highestshielding effectiveness with an average SE of 42 dB, and the fabric with 10 dip cycles showed an average SE of 33 dB while the fabric with 5 dip cycles exhibited an average SE of 20dB. These results indicate that increasing the number of dip cycles enhances the shielding effectiveness of the MXene coated fabrics. The VNA measurements showed that the EMI shielding properties of the MXene-coated fabrics remained stable. As a result, Mxene shows exceptional shielding of EMI with increased SE which depends on the number of coatings, good fabric durability and has a greater structural characteristic.

Overall, MXene-coated fabrics represent a promising avenue for addressing the growingdemand for effective EMI shielding solutions, offering lightweight, flexible, and durable alternatives to traditional shielding materials. Continued research and development in this field will contribute to the advancement of wearable electronics, smart textiles, and other applicationswhere EMI shielding is critical.

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