euspen's 25th International Conference & Exhibition, Zaragoza, ES, June 2025
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Manufacturing of Nano Thin Film Biomedical Sensors and In-Situ Bending Electrical Characteristic Analysis

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Abstract

With the rapid global aging of the population, many researchers are striving to establish sustainable socio-technical systems using biomedical sensors in living labs. In particular, the use of skin-attachable biomedical sensors is increasing for monitoring the vital signs of patients with mobility difficulties in real-time. In addition, for accurate conversion of bio-signals into electrical signals, it is important that the electrical properties remain stable during use and consistent with their initial state. In this study, we developed a method for fabricating nano thin film biomedical sensors that can be attached to the skin and proposed an in-situ method to analyse changes in the electrical properties of the bended sensor. The electrical signal detection component was fabricated using MXene(two-dimensional inorganic compounds), a material with excellent electrical conductivity even at thin thicknesses and the ability to be fabricated on flexible polymer substrates. High-purity Ti_3C_2 MXene was synthesized by selectively etching aluminum from the Ti_3AlC_2 precursor. The MXene was then spray-coated onto a flexible Polyethylene Terephthalate substrate to a thickness of 0.040µm, resulting in a sensor with an approximate thickness of 0.1mm. Assuming the sensor is attached to a finger, we proposed a jig for in-situ observation of crack formation in the sprayed MXene under bending conditions within a scanning electron microscope. This process enabled the analysis of density and width of the cracks generated during bending. Additionally, changes in electrical characteristics from the flat state to the bending state were analysed using a multimeter to measure variations in resistance, a key electrical property. The generated cracks and resistance changes were confirmed to have a correlation with crack factors. Based on these results, we proposed an in-situ bending analysis method for skin-attachable nano thin film biomedical sensors.

Biomedical, Manufacturing, Electrical Characteristic, In-Situ

1. Introduction

The challenges of a rapidly aging population are driving the demand for advanced healthcare technologies, accelerating the development and application of biomedical sensors in living labs to enhance health monitoring and management[1, 2]. Among these, skin-attachable biomedical sensors are gaining recognition as a useful technology for real-time monitoring of bio-signals such as heart rate[3], glucose[4], and motion[5]. For such sensors to be attached to the skin, they must be thin and flexible to conform to the skin's natural movements. At the same time, the sensors must ensure stability and reliability in their electrical properties as they convert bio-signals into electrical signals. Considering these necessities, we aim to manufacture a nano thin film biomedical sensors using MXene, a 2D transition metal carbide known for its flexibility and electrical conductivity[6]. Furthermore, we proposed an in-situ analysis method to evaluate changes in electrical properties by assuming the fabricated MXene sensor was bended and attached to a finger and steadily.

2. Materials and methods

2.1. MXene film

To fabricate MXene, which is a layered compound composed of transition metal 'M' and carbon or nitrogen atoms 'X', the precursor MAX powder (Ti_3AlC_2) was selectively etched with a mixed solution of HF and HCl to remove the Al layer, resulting in the delamination of MXene (Ti_3C_2). The delaminated MXene was washed with deionized (DI) water to neutralize the pH. The delaminated MXene (Ti_3C_2) was mixed with DI water and ethanol to prepare an MXene solution, which was uniformly spray-coated onto a 107µm thick PET (Polyethylene Terephthalate) substrate. The coating thickness was 0.040µm, and the final sensor thickness was approximately 107.04µm.

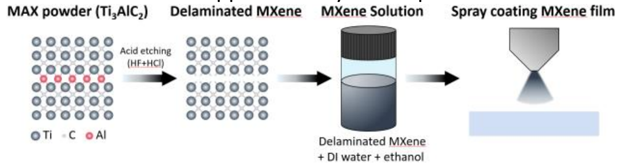

Figure 1. The schematic process flow for the manufacture of MXene (Ti_3C_2) film and sensor

2.2. In-Situ Analysis of Bending Electrical Characteristics

To investigate the electrical characteristics of the nano thin film sensor under mechanical bending, the resistance, inversely proportional to electrical conductivity, was measured. To achieve this, a custom-built bending stage capable of applying bending at various radii to the specimen was designed and utilized. The resistance of the sensor was measured using a multimeter before, under, and after bending with a bending radius of 5 mm. Additionally, to conduct in-situ analysis of the surface changes of MXene under bending states, a jig was designed and implemented inside a scanning electron microscope (SEM) to bend the sensor. In particular, cracks formed on the surface under bending, and the width and density of these cracks were closely measured and observed after bending to analyze the relationship between crack factors and resistance.

3. Results and discussion

When the MXene sensor manufactured by spray coating was bent once with a bending radius of 5 mm which is similar to one of a finger, as shown in Figure 2, the resistance increased by 97% compared to the before bending (flat) state. Even after returning to the flat state following bending, the resistance remained 59% higher than in the before bending state.

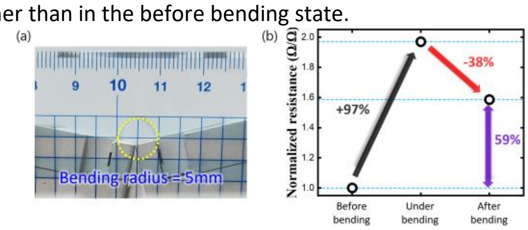

Figure 2. (a) Optical image of the MXene sensor fixed at a bending radius of 5mm using the designed a custom-built bending stage , (b) Normalized resistance of the MXene sensor before, under and after bending conditions

The SEM images in Figure 3(a) were used to visually examine the crack formation process by comparing the surface conditions across bending states. No linear defects similar to cracks were observed before bending, however, created cracks were observed perpendicular to the bending direction under bending state. These cracks were clearly classified into two types: bright cracks and dark cracks in Figure 3(b). When the sensor returned to the flat state, the behavior of crack factors varied depending on the type of crack. Bright cracks were characterized as irreversible cracks due to their unchanged width and density after bending, while dark cracks, which exhibited recovery through a reduction in width and density, were classified as reversible cracks. The reversible behavior of dark cracks is believed to contribute to the partial recovery of cracks, resulting in a decrease in resistance.

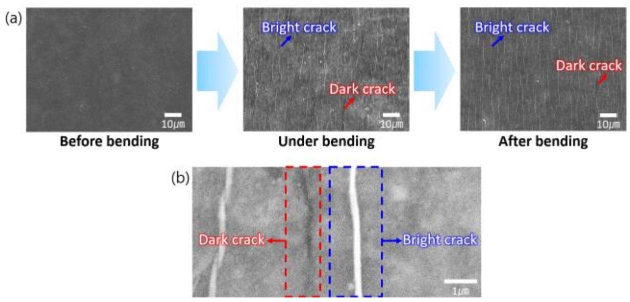

Figure 3. (a) SEM images of the surface and cracks of the MXene sensor in the before bending, under bending, and after bending states, (b) Magnified SEM image with adjusted brightness and contrast to clearly distinguish bright and dark cracks.

As shown in Figure 4, voids are uniformly distributed across the MXene film due to the characteristics of the spray coating process. As a result, even if the same strain is applied uniformly to the entire sensor, the stress distribution may vary depending on the location of the voids. In areas with high stress, new bright cracks form throughout the entire depth of the MXene layer to relieve the stress. Conversely, in areas with low stress, shallow dark cracks are generated on the surface, and these cracks can recover when the sensor returns to its original shape.

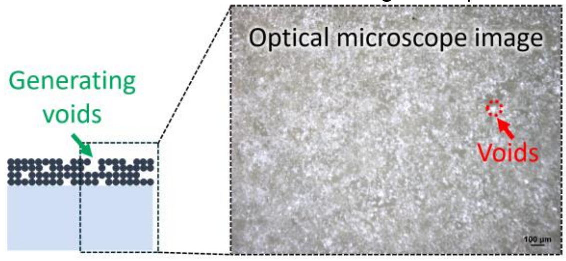

Figure 4. Schematic diagram and optical microscope image of the MXene film surface

When manufacturing biomedical sensors using MXene, it is crucial to consider the impact of cracks that increase resistance in advance to ensure the electrical reliability of the sensor. Therefore, the sensor system can be designed based on the increased resistance caused by bending, or the sensor can be manufactured by reducing the number of voids to minimize resistance changes during bending. Further research will be conducted to achieve these goals.

4. Conclusions

We manufactured a thin and flexible nano thin film biomedical sensor based on MXene and conducted in-situ electrical characteristic analysis under bending deformation. As a result, the stress distribution on the sensor surface was inhomogeneous due to uniformly distributed voids, and cracks with different properties (bright cracks and dark cracks) were generated. As the sensor returned to the flat state, some of the dark cracks among the cracks partially recovered, leading to changes in resistance and ultimately resulting in inconsistent electrical performance. In future research, we plan to manufacture a flexible biomedical sensor capable of measuring body temperature or pulse and apply bending deformation to evaluate its electrical reliability, particularly resistance variations and surface crack behavior, through in-situ analysis.

Acknowledment

This research was supported by the Nano & Material Technology Development Program through the National Research Foundation of Korea(NRF) funded by Ministry of Science and ICT (RS-2024-00408180).

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