CELLULOSE SMART MATERIAL: ITS PRINCIPLE AND APPLICATIONS

Jaehwan Kim, Mohammad Maniruzaman, Sungryul Yun and Sang Yeol Yang

Center for EAPap Actuator, Inha University, Incheon 402-751, South Korea

Introduction

Cellulose is one of the most abundant natural polymers on earth [1]. Since cellulose is environmentally friendly, renewable and biocompatible material, it has been utilized for many applications including the immobilization of proteins, antibodies, coatings, artificial artery and organs as well as the formation of cellulose composites with synthetic polymers and biopolymers. Recently, cellulose paper has been discovered as a smart material, termed as electro-active paper (EAPap), that can be used as sensors and actuators [2]. EAPap has many advantages in terms of lightweight, dryness, low cost, biodegradability, large deformation, low actuation voltage and low power consumption. EAPap is electrically activated due to a combination of ion migration and piezoelectric effect. Piezoelectric effect in cellulose has been reported long time ago, although its effect was small [3]. Piezoelectricity in cellulose is originated from dipolar orientation and monoclinic crystal structure of cellulose. Its maximum actuator performance, however, is shown at high humidity condition, and the actuator performance tends to degrade with time. As attempts to improve the performance of EAPap actuator, polypyrrole and polyaniline conductive polymer coating on cellulose EAPap, mixing carbon nanotubes with cellulose, cellulose-chitosan blending [4] have been made. As a result, dry and durable EAPap actuator that can be actuated in an ambient humidity condition has been made.

In this paper, we further investigate its structural characteristics of cellulose EAPap in terms of morphology and actuation behavior.

Experimental

Materials

Cellulose EAPap was made by dissolving cellulose pulp and regenerating it followed by film casting metal coating on it [5]. As a basic cellulose material, Cotton pulp (Buckeye) was used to prepare the cellulose solution. The prepared cellulose solution was uniformly coated on a glass plate by tape casting. The solution was cured in prepared solvent mixture. To align cellulose chains with uniaxial direction, the film was drawn at wet state by designed stretching system with different drawing ratio. The film was dried by exposing it to a heater. Fig. 1 shows the fabrication process of cellulose EAPap.

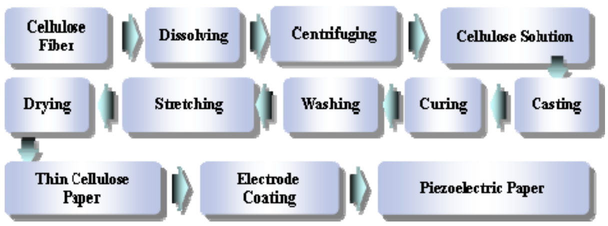

Fig. 1. Cellulose EAPap fabrication process.

Characterization

Crystallinity of cellulose EAPap was characterized by taking X-ray diffractogram (XRD) and scanning electron microscope (SEM) image was taken for the morphology. Cellulose EAPap was prepared by coating gold electrodes on both surfaces of regenerated cellulose film. The size of cellulose film is 10mm (Width) x 40mm (Length). To evaluate the actuator performance of the samples, bending displacement of EAPap was measured by using a high resolution laser displacement sensor.

Results and Discussion

Structure

Fig. 2 shows the cross-sectional images of stretched cellulose films according to drawing ratios. As the stretching ratio increased, the diameter of cellulose fibrils decreased.

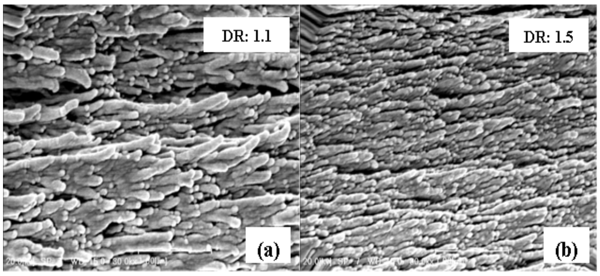

Fig. 2. SEM cross-sectional images of stretched cellulose film along with drawing ratio.

Actuation Principle

In order to make an actuation model of EAPap, we used the ion-migration model and multi-layered piezoelectric beam model. Experimental test has been performed to verify the mathematical model. In Fig. 3, the simulation result by the model is well followed the experimental result.

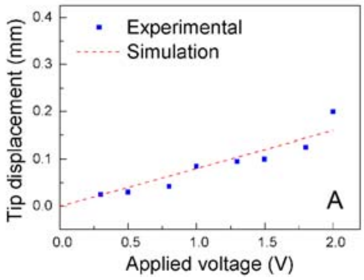

Fig. 3. Comparison of bending displacement from simulation model and the experimental results.

Applications

Cellulose EAPap is a candidate material for biomimetic actuators such as insect-like flying robot and micro crawling robot due to its suitable characteristics that are low power consumption, lightweight, large deformation and bio-compatibility/degradability. Since Cellulose EAPap has piezoelectricity generating electric field against applied deformation, it can be easily adapted to physical sensor applications for strain, force, vibration and acceleration measurements. Cellulose EAPap is one of candidate for flexible speaker with high mechanical and thermal property as well as it is eco-friendly material. Film type cellulose EAPap speaker has been made with cellulose EAPap (Fig. 4A). Also, cellulose EAPap can be used for a surface acoustic wave device resulting in the cost effective and flexible device (Fig. 4B).

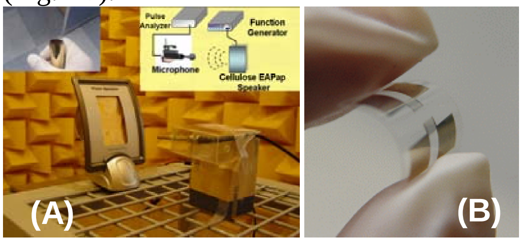

Fig. 4. EAPap based acoustic devices (A) paper speaker (B) SAW device.

Conclusion

We investigated structural characteristics of cellulose EAPap. Cellulose EAPap material was customized by stretching, regenerating cellulose and washing process. Since cellulose EAPap is biodegradable, biocompatible and cheap, it can bring broad technology impact in many areas.

Acknowledgement

This work was supported by NRF/MEST Creative Research Initiatives (EAPap Actuator).

References

1. C.D. Klemm, B. Heublein, H.P. Fink, and A. Bohn, "Cellulose: Fascinating Biopolymer and Sustainable Raw Material", *Angew. Chem. Int. Ed.*, vol.44, pp.3358-3393, 2005.
2. J. Kim, S. Yun, and Z. Ounaies, "Discovery of Cellulose as a Smart material," Macromolecules, vol.39, pp.4202-4206, 2006.
3. V.A. Bazhenov, *Piezoelectric Properties of Woods*, Consultants Bureau, New York, 1961.
4. J. Kim, S.D. Deshpande, S. Yun, and Q. Li, "A comparative study of conductive polypyrrole and polyaniline coatings on electro-active papers", *Polym J*, vol.38, pp.659-668, 2008.
5. S. Yun, Y. Chen, J. Nayak, and J. Kim, "Effect of solvent mixture on properties and performance of electro-active paper made with regenerated cellulose", *Sensors and Actuators B: Chemical*, vol.129, pp.652-658, 2008.