Cellulose Nanofibril Composite Substrates for Flexible Electronics

Abstract. *Flexible electronics have a large number of potential applications, including malleable displays and wearable computers. Current research into high-speed, flexible electronic substrates uses plastics for the flexible substrate, but these plastics typically have drawbacks, such as high thermal expansion coefficients. Transparent films made from cellulose nanofibrils (CNFs) have low thermal expansion and therefore the potential to serve as substrates for flexible electronics. Initial results show that cellulosic nanomaterials are promising candidates for electronic substrates, and research into the characterization of these substrates and their interactions with electronic devices is ongoing [1].*

Keywords. Nanofibrils, composites, flexible electronics.

Ronald Sabo[1], Jung-Hun Seo[2] and Zhenqiang Ma[2]

[1]USDA Forest Service, Forest Products Laboratory
[2]University of Wisconsin-Madison, Department of Electrical and Computer Engineering

Introduction. The demand for mobile computing continues to rise, and more than 1.5 billion mobile devices were shipped in 2011 [2]. Mobile computing devices have already had a significant impact on the print media market, and displacement of printed media by electronic devices is expected to increase. Flexible electronics especially have potential applications as displays, solar cells, smart cards, radio frequency (RF) tags, and medical implants [3].

Recent advances have demonstrated enormous potential for high-speed flexible electronics [3,4]. Researchers recently demonstrated the ability to transfer silicon nanomembranes onto flexible plastic substrates to create thin-film transistors having a 12 GHz maximum oscillation frequency [4]. Such speeds suggest a wide range of potential applications, including RF identification devices and wearable radios.

Although enhanced transfer and lithography techniques can provide reduced feature sizes, the large thermal expansion coefficients of plastic substrates present a challenge in terms of dimensional stability and thus for the long-term, practical performance of high-speed flexible electronics. Cellulose nanofibril composites offer good mechanical properties and low thermal expansion [5–7] and have the potential to serve as substrates for flexible electronics. Researchers have previously demonstrated the use of cellulose nanofibril composites as substrates for low-speed flexible displays [7]. However, these devices rely on the deposition of organic light-emitting diodes onto flexible substrates, resulting in devices with severe performance limitations. This work demonstrates the potential of CNF composites as a substrate for flexible electronics for high-speed applications.

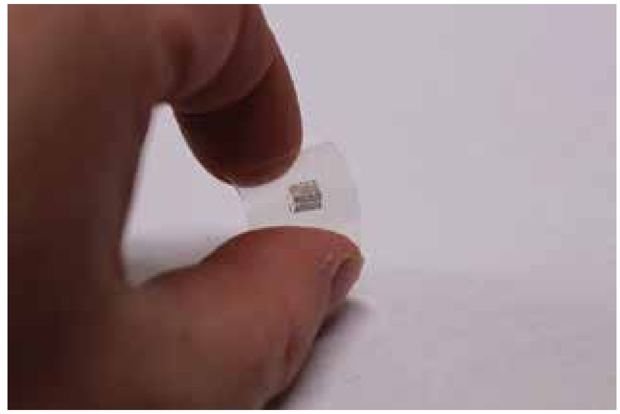

Figure 1. *Photograph of electronic device on a CNF substrate.*

Methodology. Cellulose nanofibrils prepared from wood pulp by multiple methods have been used to make substrates for flexible electronics, although the characteristics of these different types of nanofibrils have yet to be explored. Films are prepared either by casting or by pressurized filtration of CNF suspensions, and cast films have been found to result in much smoother surfaces, which is desirable for transfer of silicon nanomembranes.

Cellulose nanofibril-epoxy composites were created by laminating CNF films with a bisphenol A-based epoxy resin system. The epoxy was coated onto the CNF film, and the epoxy was cured under heat and pressure. In some cases, mirror-polished plates were used to yield smooth surfaces.

The fabrication of thin-film transistors using silicon nanomembranes (SiNM) on flexible substrates has been previously described [8], and the process used for this

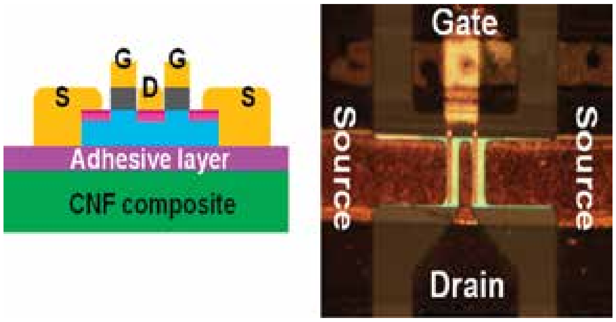

Figure 2. *Schematic and micrograph of the final TFT device. S: source; G: gate; D: drain.*

study is summarized here. Nanomembrane strips were first prepared from commercially available silicon-on-insulator wafer substrates. The source and drain contacts were then created on the nanomembranes before deposition to the CNF composite substrate. The substrate was cleaned prior to transferring the nanomembranes, and UV-curing epoxies were used to attach them to the substrate. The device was isolated by dry plasma etching with SF_6. The gate stack was formed by e-beam evaporation followed by an acetone washing lift-off process and consisted of 130 nm of amorphous silicon monoxide (SiO), 5 nm of Ti, and 170 nm of Au. Finally, the source and drain metal contacts were created.

Results. A photo of an electronic device on a CNF substrate is shown in Fig. 1. A schematic and micrograph of a thin-film transistor on a CNF substrate are shown in Fig. 2. The direct current (DC) characteristics of the transistor were tested and found to operate as expected [1]. Research is ongoing to evaluate the performance of the electronic devices and to determine how they interact with the cellulose substrates.

Conclusions. The first example of using cellulose nanofibril composite substrates for flexible electronics made by transferring silicon nanomembranes was demonstrated by fabricating and testing a working thin-film transistor. The cellulose nanofibril composite showed good chemical and thermal resistance, which is necessary for electronic fabrication. A number of challenges and uncertainties remain to be resolved. However, the use of cellulose nanofibrils as a sustainable component for high-speed flexible electronics is extremely promising.

References

[1] Sabo, R., Seo, J.-H., Ma, Z. Cellulose nanofibril composite substrates for flexible electronics. Proceedings, 2012 TAPPI International Conference on Nanotechnology for Renewable Materials.

[2] IDC Press Release. Worldwide mobile phone market maintains its growth trajectory in the fourth quarter despite soft demand for feature phones. February 1, 2012. http://www.idc.com/getdoc.jsp?containerId=prUS23297412. Last accessed May 14, 2012.

[3] Qin, G., Yuan, H. Yang, H., Zhou, W., Ma, Z. High-performance flexible thin-film transistors fabricated using print-transferrable polycrystalline silicon membranes on a plastic substrate. Semiconductor Science and Technology, 26(2); 025005 (2011)..

[4] Sun, L., Qin, G., Seo, J.-H., Celler, G. K., Zhou, W., Ma, Z. 12-GHz thin-film transistors on transferrable silicon nanomembranes for high-performance flexible electronics. Small 22(6):2253–2557 (2010).

[5] Okahisa, Y., Yoshida, A., Miyaguchi, S., Yano, H. Optically transparent wood-cellulose nanocomposite as a base substrate for flexible organic light-emitting diode displays. Compos. Sci. Technol. 69:1958–1961 (2009).

[6] Nogi, M., Iwamoto, S., Nakagaito, A. N., Yano, H. Optically transparent nanofibril paper. Adv. Mater. 20:1–4 (2009).

[7] Nakagaito, A. N., Nogi, M., Yano, H. Displays from transparent films of natural nanofibrils. MRS Bulletin, 35:214–218 (2010).

[8] Yuan, H-C. and Ma, Z. Microwave thin-film transistors using Si nanomembranes on flexible polymer substrate. Appl. Phys. Lett. 89, 212105 (2006).

Production and Applications of Cellulose Nanomaterials

Compiled and Edited by:
Michael T. Postek
Robert J. Moon
Alan W. Rudie
and
Michael A. Bilodeau

Cellulose nanocrystals incorporated within the overcoat varnish of the cover!

TAPPI PRESS
15 Technology Parkway South
Suite 115
Peachtree Corners, GA 30092 U.S.A.
www.tappi.org

ISBN: 978-1-59510-224-9
TAPPI PRESS Order Number: 0101R332
Printed in the United States of America