OLEDs, OXIDE TFTs, AND DISPLAY WEEK PREVIEW ISSUE

Information DISPLAY

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Official Monthly Publication of the Society for Information Display • www.informationdisplay.org

Mar./Apr. 2013
Vol. 29, No. 2

SID Honors & Awards – Recognizing Innovation



ADVANCES IN OLED TECHNOLOGY, PROCESSES, AND INFRASTRUCTURE

EXPLORING THE POTENTIAL OF OXIDE TFTs

RECENT DEVELOPMENTS IN FLEXIBLE ELECTRONICS

Plus

What You Missed at CES 2013

Display Week First Look

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ON THE COVER: *This year's winners of the Society for Information Display's Honors and Awards include* ***Dr. Isamu Akasaki,*** *who will receive the Karl Ferdinand Braun Prize;* ***Mr. Marc Baldo,*** *who will be awarded the Jan Rajchman Prize;* ***Dr. Hoi-Sing Kwok,*** *who will be awarded the Slottow–Owaki Prize; and* ***Dr. Shigeo Mikoshiba,*** *who will receive the Lewis & Beatrice Winner Award.*



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- Optical Dry Bonding
- AMOLED-Panel Market

INFORMATION DISPLAY (ISSN 0362-0972) is published 6 times a year for the Society for Information Display by Palisades Convention Management, 411 Lafayette Street, 2nd Floor, New York, NY 10003; William Klein, President and CEO. EDITORIAL AND BUSINESS OFFICES: Jay Morreale, Editor-in-Chief, Palisades Convention Management, 411 Lafayette Street, 2nd Floor, New York, NY 10003; telephone 212/460-9700. Send manuscripts to the attention of the Editor, *ID*. SID HEADQUARTERS, for correspondence on subscriptions and membership: Society for Information Display, 1475 S. Bascom Ave., Ste. 114, Campbell, CA 95008; telephone 408/879-3901, fax -3833. SUBSCRIPTIONS: *Information Display* is distributed without charge to those qualified and to SID members as a benefit of membership (annual dues $100.00). Subscriptions to others: U.S. & Canada: $75.00 one year, $7.50 single copy; elsewhere: $100.00 one year, $7.50 single copy. PRINTED by Wiley & Sons. PERMISSIONS: Abstracting is permitted with credit to the source. Libraries are permitted to photocopy beyond the limits of the U.S. copyright law for private use of patrons, providing a fee of $2.00 per article is paid to the Copyright Clearance Center, 21 Congress Street, Salem, MA 01970 (reference serial code 0362-0972/13/$1.00 + $0.00). Instructors are permitted to photocopy isolated articles for noncommercial classroom use without fee. This permission does not apply to any special reports or lists published in this magazine. For other copying, reprint or republication permission, write to Society for Information Display, 1475 S. Bascom Ave., Ste. 114, Campbell, CA 95008. Copyright © 2013 Society for Information Display. All rights reserved.

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Flexing and Stretching

So you work in displays? You may soon be working in flexible electronics too. Author Jason Heikenfeld, associate professor with the School of Electronic and Computing Systems at the University of Cincinnati, looks at several of the most interesting developments in flexible electronics.

by Jason C. Heikenfeld

WHEN I began my academic career in 2005, I thought my display days were over. The dominance of LCDs was clear; what research was there left to do? Was I ever wrong, as displays have remained a rich area of work for me and countless other people, and there continues to be numerous needs for novel display technologies. Since I became involved with displays more than a decade ago, I have worked with and published on just about every display type: plasma/liquid/solid, emissive/transmissive/reflective/transparent, flexible/rollable, 3-D, *etc.*

More and more, I find myself working in flexible electronics too, and the segue into flex has been quite natural. Why? Well, like many of us "display folk," I have always been intimately familiar with low-cost and large-area microfabrication, hybrid integration of organic and inorganic materials, low-temperature processing, and print-based patterning. Furthermore, to make something rollable, the foremost enabler is often to make the entire device as thin as possible, typically <100 µm thick. Display engineers are constantly looking for ways to thin down the materials in a display to bring about better aesthetic appeal, impact resistance, and the thinness and lightness required for devices such as smartphones. The point is that if you work in displays, you are often highly qualified to work in flexible/rollable electronics as well.

In this article, I hope to show that others in the display community a few things they may have not seen before by touching on some of the interesting things happening in flexible/stretchable electronics. This is not a comprehensive review by any stretch (or flex); rather, I hope to convince readers that flex is a growing and exciting area with applications that might complement more traditional work in displays by citing some examples of this work being done in the industry.

PARC: A logical place to begin this sampling is the Palo Alto Research Center (PARC), a prime source of display and print experts flexing their muscles (or devices) in the flexible-electronics area. PARC was an early pioneer in the late 1990s in flexible-display technology, due, in part, due to efforts in Gyricon's bichromal ball technology for electronic paper (a rotating charged ball with black on one side and white on the other), and also, in part, to its deep expertise in print-based patterning. If you look at PARC's activities today (Fig. 1), you will see a broad spectrum of flexible electronic technologies ranging from flexible batteries with a bend radius of <3 mm and a capacity >5 mA-hr/cm^2, jet-patterned active-matrix backplanes (680-µm pixels), and a flexible 75-dpi PIN image sensor array, just to name a few. PARC develops these technologies through a variety of projects ranging from basic materials science all the way to full systems prototyping/demonstration. According to Janos Veres, Program Manager for Printed Electronics at PARC, "Flexible and printed electronics is a field rich in opportunities for PARC to deliver high-value innovation by combining its expertise in material science, device and circuit design, process technology, and prototyping. Our clients range from chemical companies to makers of consumer products." A great deal of PARC's pioneering work in printed displays is now being deployed in exploring the limits of printed circuits and their use, for example, in smart sensor systems. PARC has recently demonstrated printed, disposable, blast dosimeters that monitor traumatic brain injury in soldiers on the battlefield. The tape-like blast dosimeter records the severity and the number of blast events during 1 week in order to enable early administration of medical care. The fully functional sensors are fabricated by methods such as lamination, die cutting, solution processing, and printing – all compatible with inexpensive roll-to-roll processing.

American Semiconductor and MC10: Let's say that you are a display integrated circuit or row/column driver expert, and you are excited about chip-on-glass, but think that flex has nothing to do with you or with a traditional CMOS foundry. Think again! Today, the very high temperatures and ultra-high-resolution capabilities found in Si foundries can be realized in rollable form. Compared to conventional flexible thin-film-transistors (TFTs), you can obtain a few 100× improvements: an increase in the best mobili-

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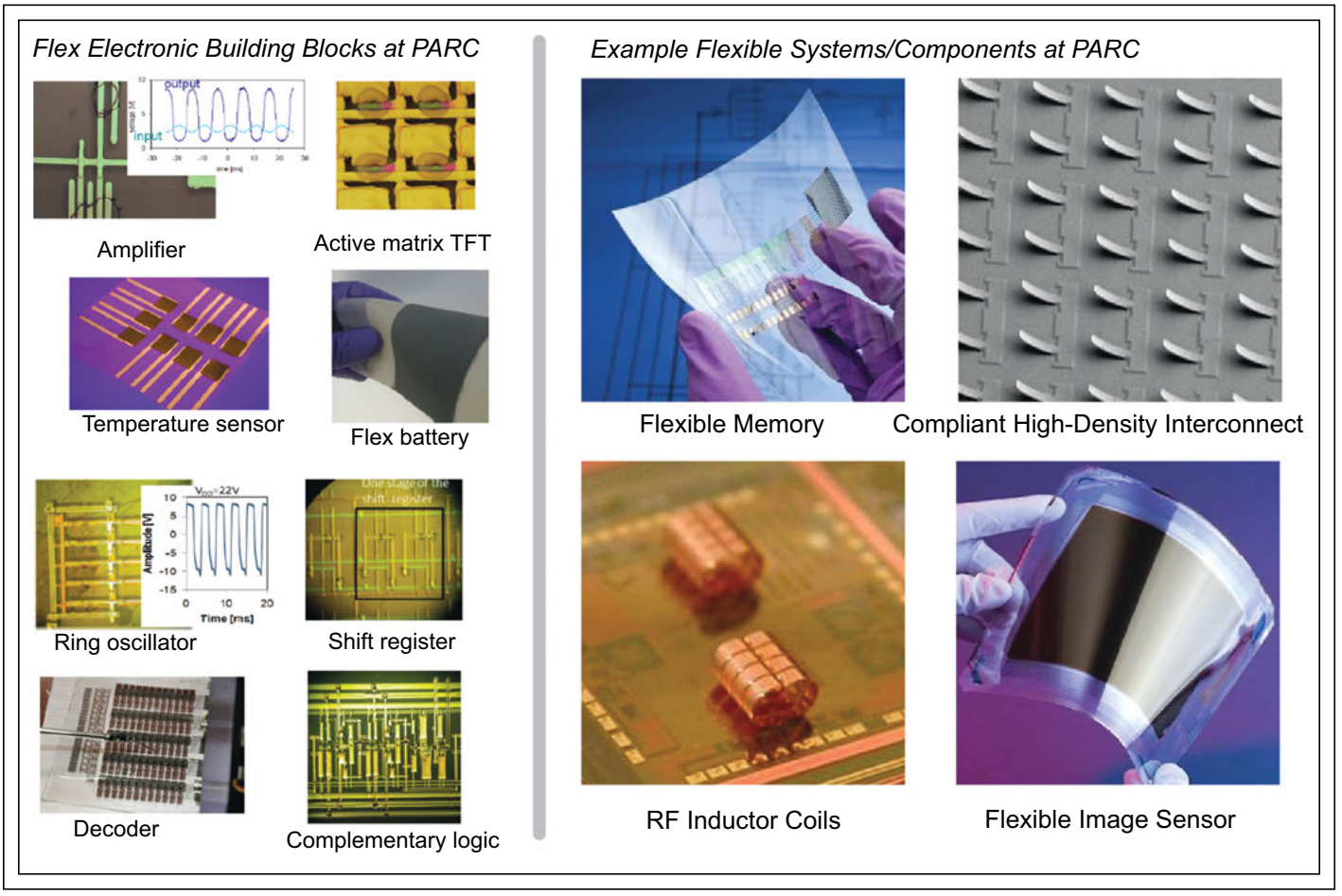


Fig. 1: *PARC's wide spectrum of foundational flexible electronic components and systems include a growing library of additively printed devices and circuits, novel approaches for compliant packaging of components, and flexible sensor arrays. Source: PARC.*

ties for amorphous transistors on plastic from ~1 cm^2/V-sec to ~100s of cm^2/V-sec for crystalline Si and a reduction in the feature sizes from approximately 5 to15 µm for display lithography down to approximately 50–150 nm. The key enabler for flexing is the same: make the CMOS film as thin as possible.

As shown in Fig. 2, American Semiconductor uses a wafer-thinning process on silicon-on-insulator (SOI) substrates to make flexible ICs with from 10 to 10,000s of chips per wafer. However, to reduce fragility, the company applies a polyimide film before the thinning process is performed to remove the thick Si support wafer. CMOS wafers thinned to <20 µm have been demonstrated to achieve a bend radius of 5 mm with no change in the electrical characteristics after flexing. American Semiconductor is a flexible electronics and services provider that performs flexible hybrid systems development as well as design engineering, including design, verification, layout, and testing. It now also provides FleX Silicon-on-Polymer technology for flexible CMOS. Initial production runs of its FleX technology have begun, and regarding future volume product, Richard Chaney, General Manager at American Semiconductor, notes, "FleX is a repeatable, manufacturable process demonstrated in prototype volumes and is currently supported using a Jazz Semiconductor CMOS foundry silicon. We convert advanced ICs from commercial foundries into flexible chips by using our proprietary low-cost FleX process and integrating them with printed electronics to form flexible hybrid systems. This new technology is ultra-thin, rugged, bendable, and low cost. Our FleX technology provides logic, memory, and wireless capability that is orders of magnitude faster and smaller than printed TFTs for features that have always been required but never before available in flexible electronics." So, as a side note, if you want to realize a completely rollable display with no rigid parts, you now have every component available to you in order to make this a reality.

Now, can you take flexible Si electronics one step further, making them conformal, stretchable, and biocompatible? The University of Illinois and startup MC10 have answered that affirmatively, demonstrating several exciting new conformal electronics in recent years (Fig. 3). They have shown sophisticated "epidermal electronics" that is applied to the skin in a manner similar to that of a temporary tattoo or expandable electronics on a balloon catheter for sensing or for localized delivery of therapy. The key to moving beyond flex to stretch/conformal is the ribbon-like sections

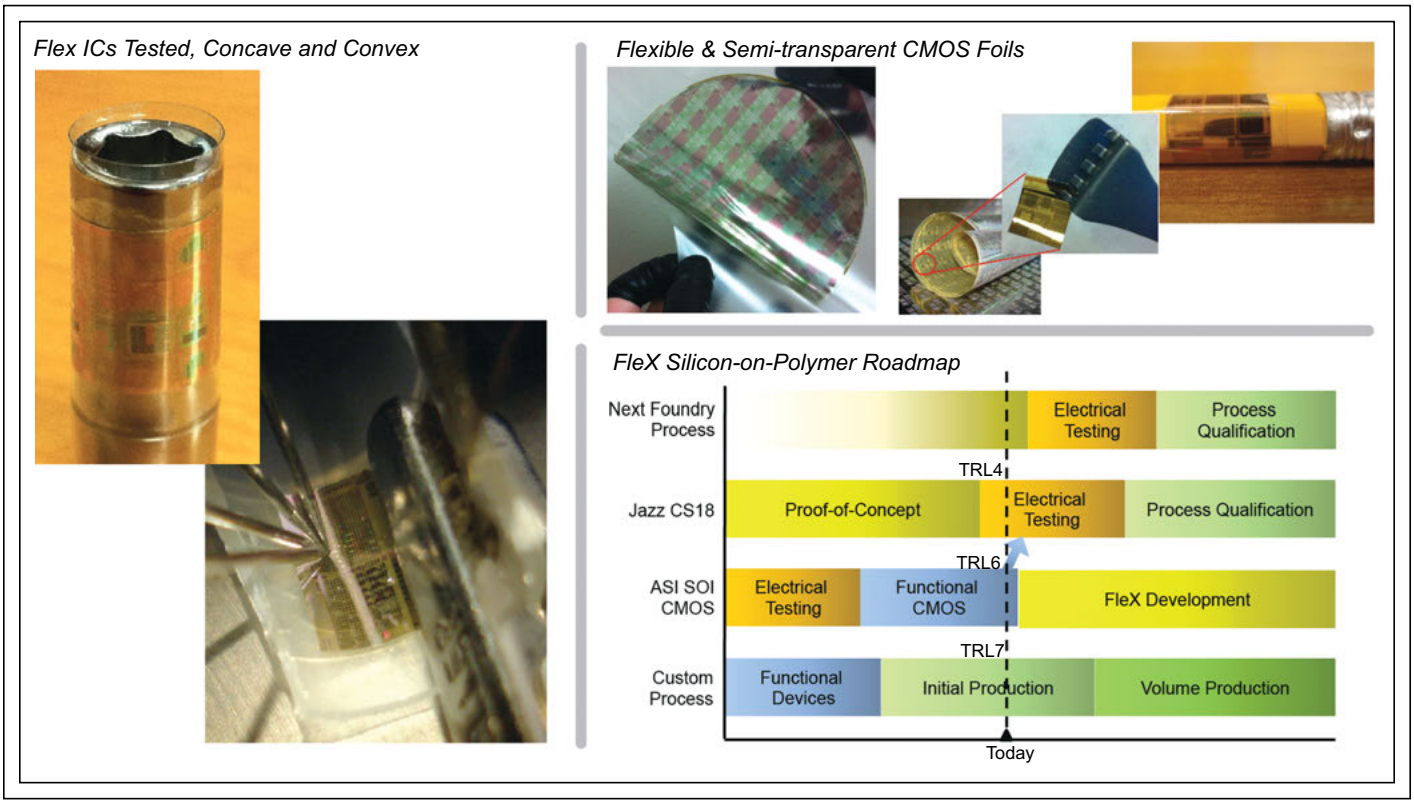


Fig. 2: *Above (left) are examples of flexible ICs based on American Semiconductor's Flexible Si CMOS (FleX) technology. At upper right are flexible, transparent CMOS foils; at lower right, the company's roadmap for developing and delivering the technology. Source: American Semiconductor.*

between functional "islands" of Si. These interconnecting ribbons have a concertina-like geometry and can be stretched by more than 50%, which is also just about how much human skin can stretch. One of MC10's mottos has been "electronics anywhere," and, more recently, the company has been focusing on reshaping electronics to conform to the human body for digital health applications. According to Amar Kendale, MC10's VP of Strategy & Market Development, "Epidermal electronics enable constant medical monitoring everywhere. MC10's ultra-thin skin-mounted sensors can manage conditions continuously so that they do not worsen or reach a crisis." This constant monitoring is made possible by using devices that are so thin that activities such as football, firefighting, or sleeping can be performed without any interference from the device, with medical data provided wirelessly via Bluetooth or other communication means.

Corning: Glass substrates are a familiar area to most of us in the display industry. Corning, Asahi, and several others have now released super-thin glass that challenges the notion that flex means low-temperature processing and the need for sophisticated moisture/gas barrier layers. Flex electronics that require dimensional and thermal stability, hermeticity, transparency, and a high surface quality on which to build may work better with flexible glass than with plastic substrates. Even polyimide substrates are not compatible with conventional poly-Si temperatures, and stainless steel has its own host of issues (such as the need for planarization). Glass, on the other hand, can be made with the fusion draw process invented at Corning, such that the outer glass surface is never touched during forming, providing a pristine surface. Dr. Sean Garner of Corning notes that "Corning Willow Glass is an enabling component for both display and non-display applications that allows for thinner, lighter weight, or conformal device designs."

Willow Glass allows processing up to 500°C and is available in samples down to a thickness of 100 µm. This certainly satisfies flexibility and bending down to several centimeters in radius and allows roll-to-roll processing (see examples performed by ITRI in Fig. 4). However, at the present time, it is not yet thin enough for personal foldable or rollable applications, a capability that currently only plastic substrates can provide. When it comes to substrates for flexible applications, your options are as follows: you can now process on conventional transparent PEN/PET flex substrates at <150°C, you can use yellow-colored polyimide which allows a bit higher temperature processing up to ~350°C and is the workhorse of all flexible electronic interconnects in the electronics industry, and now you have access to transparent glass that allows all the processing temperatures and materials that can be found in a conventional modern LCD manufacturing facility. Furthermore, as mentioned previously, the world of crystalline Si is now flexible, so there are many options.

Flex Tech: In flexible electronics, there is room for everyone (Fig. 5). Organizations such as the FlexTech Alliance (formerly the

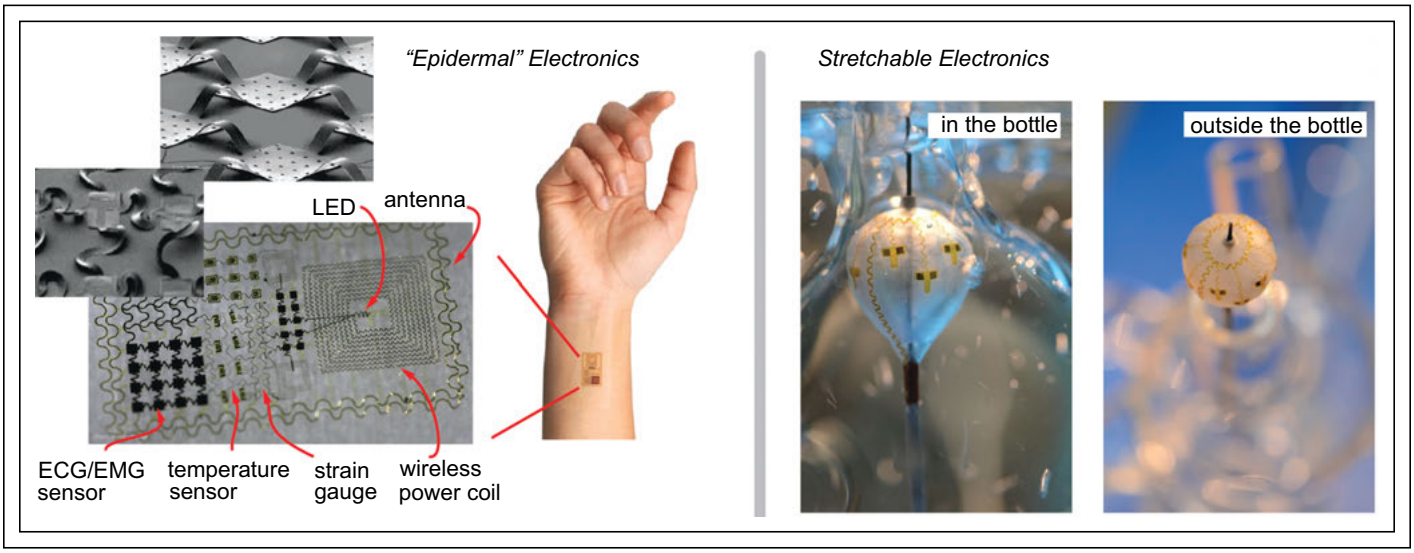


Fig. 3: *State-of-the-art medical applications for flex Si incorporate specially designed "ribbons" in between functional Si "islands" to allow fully conformal, even stretchable, electronics.*

U.S. Display Consortium) and the market research firm IDTechEx in Europe broadly cover flexible electronics, and, not surprisingly, many of their reports include developments in displays. FlexTech's view of major flexible-electronics opportunities is two-fold: (1) flexible and printed electronics enable human-scale products – conformable, portable, or wearable – for healthcare, energy, and displays/e-books and (2) new, distributed manufacturing with printed electronics is possible for customized, diversified products. These will be manufactured closer to the end user and will be accessible to both large and small manufacturers. There is no doubt in the market either. Consider these highly compelling market forecasts by IDTechEx: "The market for printed and thin-film electronics will be $9.46 billion in 2012; 42.5% of that will be predominately organic electronics such as OLED display modules. Of the total market in 2012, 30% will be printed. Initially, photovoltaics, OLED displays, and e-paper displays grew rapidly, followed by TFT circuits, sensors, and batteries. By 2022, the market will be worth $63.28 billion, with 45% printed and 33% of that on flexible substrates."[1]

So How Close Are We?

Compelling, exciting, and transformative are all good descriptors of some the technology demonstrations now being seen in flexible electronics. So what is holding us back? Well, as we know for applications such as displays, in some cases it is a technological hurdle (stable TFTs and no moisture penetration for flexible OLEDs) and sometimes it is market pull. (Polymer Vision's beautiful rollable displays relied on E Ink's monochrome reflective technology, which in those days lacked the response time suitable for video rates. This

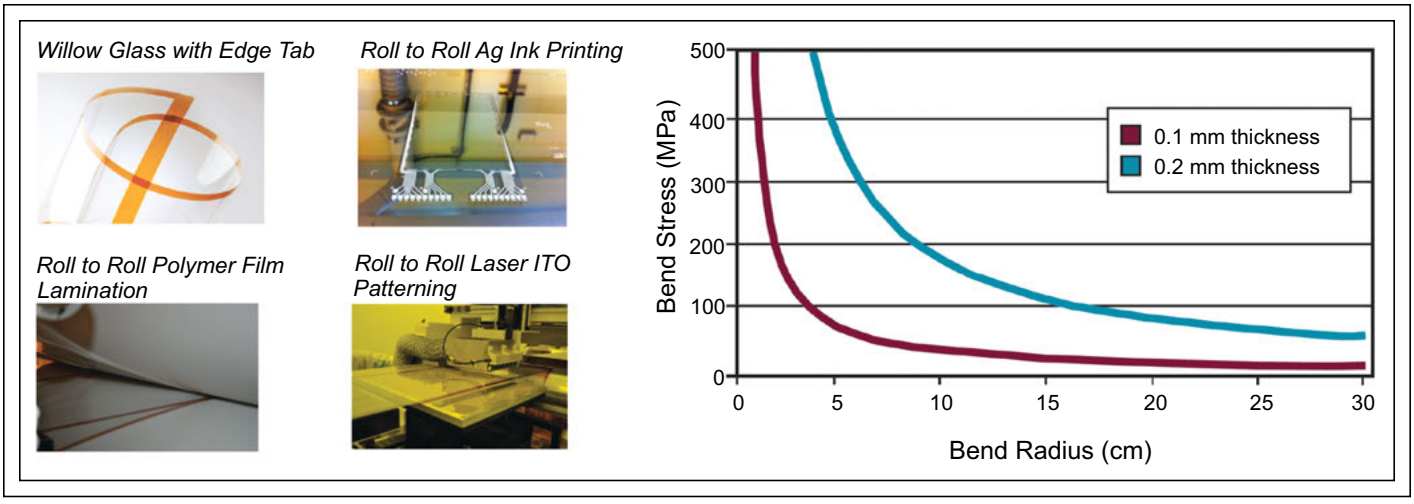


Fig. 4: *Above are examples of roll-to-roll processes implemented by ITRI (Taiwan) on Corning's flexible Willow Glass, and, at right, a plot of bend stress vs. bend radius.*

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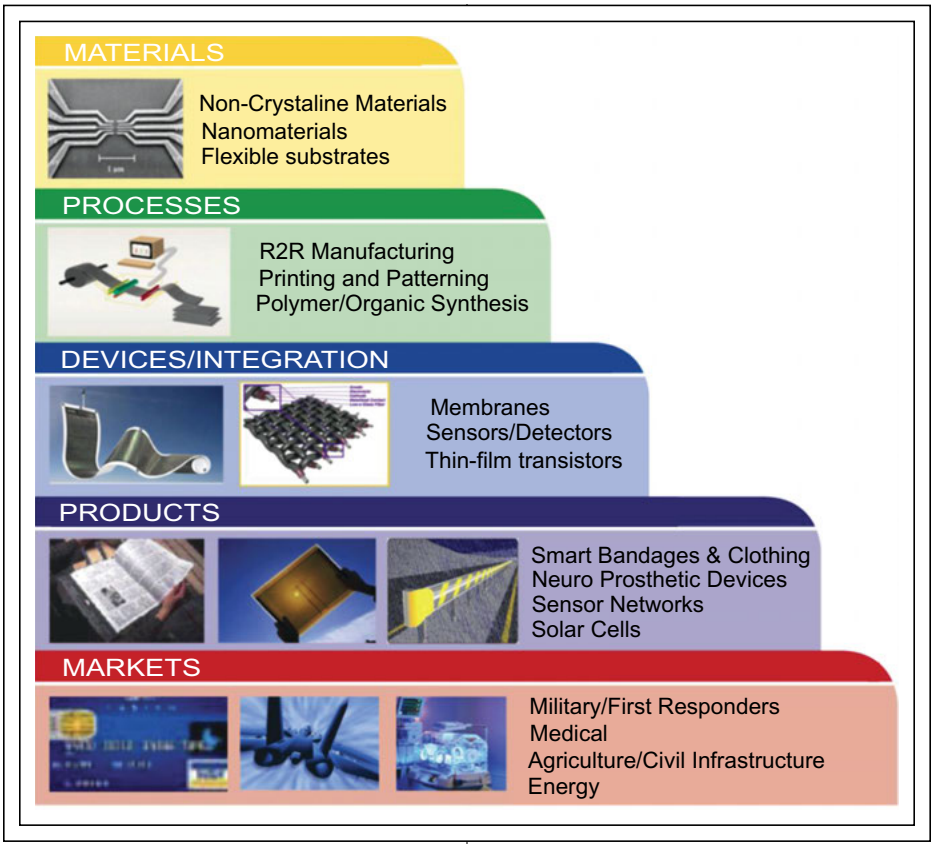


Fig. 5: A view of flexible/printed electronics materials, products, and markets as shown by the FlexTech Alliance.

shortcoming may have allowed touch-screen smartphones and tablets with full-color LCDs to absorb consumer demand for the potential rollable product.) Since the polarizers used for LCDs cause the panels to be too thick for use in a rollable display. The future may be limited to rollable OLED displays or e-Paper; however, smartphones do not need to wait for rollable displays to switch over to simple flex for thinness and impact resistance.

Other technologies such as flexible electronics for medical applications have great momentum toward commercialization, but gaining acceptance and approval in medical devices involves a long pathway with numerous regulatory and other hurdles that must be cleared. Roll-to-roll manufacturing has been fully proven as well, including ITRI's demonstration several years ago of all the electronics needed to enable a smart-card device. The fundamentals and infrastructure for flexible electronics are quite sound, and continued work is needed in finding the right applications. You often have to provide something highly desirable to consumers that they will pay extra for, since at the time of market entry, the competition is rigid electronics, which have beaten the difference between manufacturing cost and price down to a razor-thin margin. Only in the longer term will low-cost arguments such as roll-to-roll manufacturing potentially allow for more flex products to win market share based on cost alone.

So, again, do you work in displays? How long will it be before you work in flexible electronics too? It may be sooner than you realize. It is quite clear that whether your interest is in displays or in other areas of flexible electronics, exciting enabling technologies are now available, and flexible electronics and displays will become ever more pervasive in our work and daily lives.

Reference

[1]http://www.idtechex.com/research/reports/printed-organic-and-flexible-electronics-forecasts-players-and-opportunities-2012-2022-000301.asp ■