POLYMER ELECTRONICS
- FANCY OR THE FUTURE OF ELECTRONICS

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Abstract

At present, the electronic world is very much dominated by inorganic materials, in particular silicon. Organic materials in electronic devices were mostly used as insulators, so far. The history of polymer electronics started 25 years ago – firstly conductors, than semiconductors, transistors and fully functional polymer ICs. But the mobility of charge carriers in polymers is limited and incomparable to silicon. Nevertheless, polymer electronics plays more and more important role nowadays, especially in flexible electronic. Freedom of design, compact portable products, cost-effective assembly, environment friendly materials, software based printed ICs, flexible polymer transistors – there are unquestionable advantages of flexible electronics. Key Applications Scenarios for the polymer electronics predict fully applicable displays in use (8 -10 years), embedded MEMS (2-10 years), labels for broadband wireless communication (8-10 years), polymer batteries (now – 5 years), photovoltaic cells (10 years). Probably in the future we will use Wearable Ultra Micro Computers.

1. Introduction

Main Polymers molecules formed of many identical units, bond to each other into long chains. For a polymer to be electrically conductive it must imitate a metal – the electrons in the bonds must be freely mobile and not bound fast to the atoms. In 2000 Alan Heeger, Alan MacDiarmid and Hideki Shirakawa were awarded the Nobel Prize in Chemistry for showing how polymer can be made to conduct electric current. One condition for this, is that the polymer should consist of alternate single and double bonds, termed conjugated double bonds.

At present, the electronic world is very much dominated by inorganic materials, in particular silicon. The Nobel Prize hasn't been a milestone in the progress of polymer electronics, but it showed the importance of this branch of knowledge. New word, "polytronic" has appeared in electronic vocabulary as a short name of this knowledge and quickly developed technology.

2. State of the Art

The history of polymer electronics started more than 25 years ago – firstly conductors, than semiconductors, transistors and fully functional polymer ICs. But the mobility of charge carriers in polymers is limited and incomparable to silicon. Nevertheless in the last 10 years many properties of material were improved. For example, field effect mobility could be increased from below 10^{-3} cm^2/Vs to higher than 1 cm^2/Vs both for vapour-deposition materials and for polymers and solutions which can be spin-coated. For spin-coated organic-inorganic hybrid materials up to 50 cm^2/Vs can be measured at room temperature. However, all mentioned values are only achieved for p-type materials so that the realisation of corresponding n-channel-transistors (and therefore of a complementary logic or a bipolar technology) still needs intensive research.

Simple polymer transistors were reported at the beginning of nineties. In 2001 a report was published [1] that the Polymer Electronics team at Philips Research works on 48-bit code generators, comprising about 1,000 transistors. Such ICs provide the same function as bar codes, but will in addition allow for electronic read-our any programming. Organic field effect transistors (OFETs) with regioregular poly(3-alkylthiophenes) as semiconductor and poly(4-vinylophenol) as insulator, processed by TITKF/Siemens AG group [2], show good saturation behaviour and on/off ratios from several hundred up to about 3,000. The field effect mobility is in the range of $10^{-2} \div 10^{-1} cm^2/Vs$. The same team reports the results of their work on polymer field effect transistors (PFETs). The transistors with a polyaniline/polyamide composite result on/off ratios up to about $4.7 \cdot 10^3$ [3]. Nevertheless, the use of polymer transistors in ICs is still in its infancy.

The second branch of active polymers is related to photonic applications. It was discovered thirteen years ago that some conjugated polymers exhibit electro-luminescence. The potential of this discovery for novel lighting concepts was recognized almost immediately. As the result of researcher centres and industry, a polymer LED, (named also as OLED by using a “Organic” modifier) displays appeared. Devices for use in a passive matrix OLED display (mobile phones e.g.) require a low forward voltage, high luminance efficiency, and low reverse current. They usually consist of multi-layered structures to facilitate charge injection from the contacts as well as carrier transport into the emitting layer. The luminance efficiency can be increased by doping the emitting layer with special dye molecules [4]. In bilayer devices, the electroluminescence can be controlled by thickness optimisation of the different emitting layers up to white emission [5].

Polymers in electronics are widely used as passive materials. There are etching and soldering resists, dielectrics, boards, materials for encapsulating, undefiling and coating, electrically and thermally conductive adhesives for electronic interconnecting.

3. Needs and barriers of polymer electronics

The present technology development of polymers active devices is comparable with that at the beginning of the silicon-based IC industry, some 30 years ago, but with the technology possibilities of today. In quest of cheap polytronics, researchers over the last five years have progressed from making fairly rudimentary single all-polymer transistors, to expected integrated circuits made all, or nearly all, from plastics in the future. The use of polymer electronics is opening up an exceptionally large market and is made possible by the low cost of plastic ICs. It is expected that, once the development of the production process is completed, the plastic chips can be produced at a cost price of the order of Cents per finished chip.

In order to make this vision a reality, combined research is necessary in order to overcome the actual problems. Some of them are:

- The polymeric elements are up to now not suitable for production because of the not optimised materials and fabrication techniques. The reproducibility of production is not yet given.
- The development currently still concentrates very much on the optimisation of the single elements. For the development of systems, a design environment including simulation possibilities is however urgently required.
- For production of efficient and marketable products, the integration of important elements (NMOS, bipolar transistors) has not yet been carried out.
- The materials for the packaging of the polymer electronic elements are not yet solved satisfactorily from the system aspect. A specific new and further development of passivating, moulding and connection technologies, based on hybrid materials, should positively affect the costs of the systems and their long-term stability.

4. The offer of polymer electronics

The role of polymer electronics is not primarily a replacement for existing silicon devices, but opens up the prospect of completely new applications that combine the features of transistor, LED, detector and interconnect devices with the freedom of design, flexibility and low cost of plastics. In view of these new findings it seems possible that polymers may solve present and coming problems and add new functionality to microelectronic circuits and systems. Polytronics creates a new and very promising technological area with new applications and products. Examples are:

- Full polymer transponders (RFID),
- Printable tags,
- Flexible systems,
- Disposable electronics,
- Body area networks, smart clothing wearable computing,
- Pervasive computing and communication systems,
- Electronic circuits for "polymer based" photovoltaics, detectors, imaging applications, displays, illumination systems,
- Disposable and low cost sensors (biochemical),

- Actuators,
- Disposable low cost memories (bistable).

The practical use in every days life of polytronic products offers advantages from the environmental point of view. Products based on polytronics can be manufactured with relative simple and inexpensive equipment at low cost. Other important advantages are related to the unique mechanical properties of polymers: they are light weighted and flexible, very durable and rugged under stress and flex, and can be easily applied and maintained over a large surface area. The manufacturing of polytronic-based electronic products does not have to be done in large, ultra pure, energy-devouring clean rooms. The polymer materials are used selectively where they are needed (printing) and are not wasted. The organic material can be effectively dealt with after use and in recycling. No high temperatures need to be applied in the processing of organic materials.

Not only the manufacturing possibilities but also the materials used are very promising from the environmental point of view compared to the materials used in todays electronic products: Polytronics seems to be great hope for future mobile products, the mass market of the future, because their environmental performance can be improved to a great deal by means of engineering, in contrast to the toxic properties of, for instance, many metals.

5. The nearest future: flexible electronics

A broad application field for full polymeric circuits is expected for the low-cost integration of simple data processing functions on flexible film substrates (Figure 1). Such products must be produced in very high volume. For this reason, many of the traditional wafer based manufacturing tools used in the traditional electronics manufacturing will have to be changed. Compared to the subtractive manufacturing sequence of layer deposition, lithography and etching processes, which are used in the wafer-based processes, the organic materials mostly make additive patterning techniques possible like the different printing method.

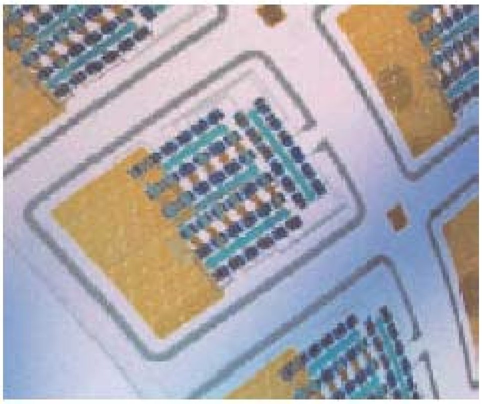

Fig.1. Flexible film substrates; source: Fraunhofer Magazin

During last few years only few promising methods for printed polymer transistor have been reported in literature. Infineon Technologies group informs [6] that they have fabricated pentacene thin film transistors on flexible polymeric substrate with gate electrodes prepared using a combination of microcontact printing and selective electroless plating of nickel. These transistors also employ a spin-coated polymer gate dielectric layer patterned by photolithography and dry etching and have a carrier mobility of 0.03cm2/Vs, comparable to pentacene transistors with vacuum-deposited gate electrodes.

Siemens Corporate Technology has presented OFETs and organic inverters based on functional polymers with single layers applied by pad and screen printing [7]. Using this technique OFETs were assembled, in which poly(3-alkylthiophene) served as the semiconductor, and poly(4-hydroxystyrene) as the insulator. Source-drain electrodes made from polyaniline and gold with channel lengths of 20μm have been patterned by pad printing. Transistor electrodes consisting of silver filled ink with channel lengths of 100μm were directly pad printed. A functional semiconductor layer was applied by screen printing, while gate electrodes have been pad printed. Also pad printing technique was used for defining of a full organic logic capable inverter. Good electrical characteristic of OFET have been obtained and the results provide the variability of pad and screen printing for polymer electronics. Both methods have the potential for development into large volume mass-production.

For flexible electronics, continuous flow, low-cost manufacturing processes with high throughput have to be used. The best seems to be reel-to-reel industrial processes (R2R), based on prints circuits on flexible substrates technique. The newest papers bring information about other processes with prospect of being applicable in R2R industrial production lines. TU Braunschweig have demonstrated an experimental process for obtaining conductive polymer patterns by electrochemical polymerisation of conductive polymers on pre-patterned electrode [8]. The polymer patterns can easily be transferred to an insulating substrate. A lateral resolution of 10μm has been obtained and the results indicate that a higher resolution on the scale of a few microns is possible.

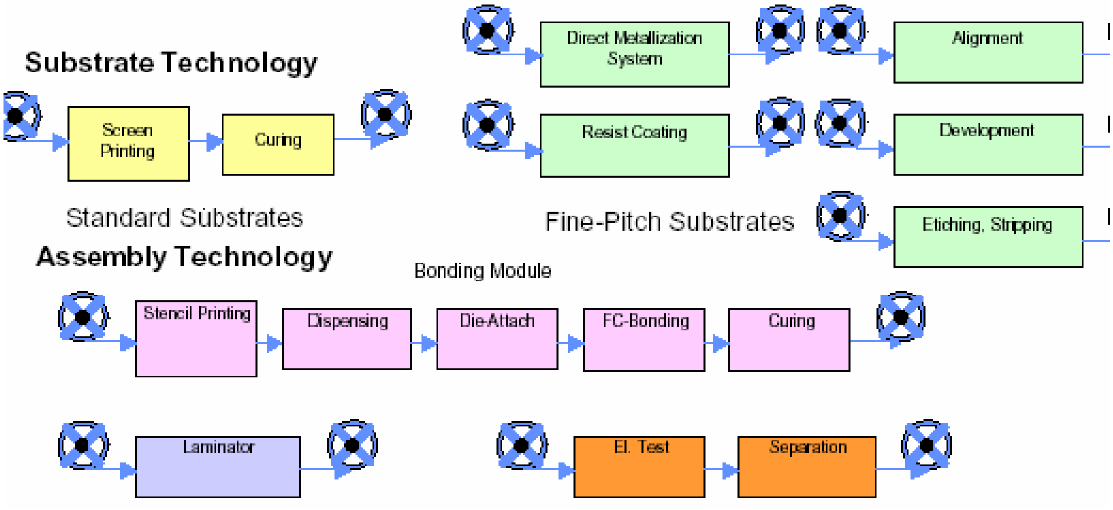

Fig.2. Modules of the Reel to Reel Application Center at IZM Munich

Fraunhofer Institut Zuverlässigkeit und Microintegration (IZM) in Munich has established the Reel to Reel Application Center. Main modules of the Center are presented in Figure 2. The idea of polymer transistors reel-to-reel processing is given in Figure 3 and low-cost MEMS – in Figure 4.

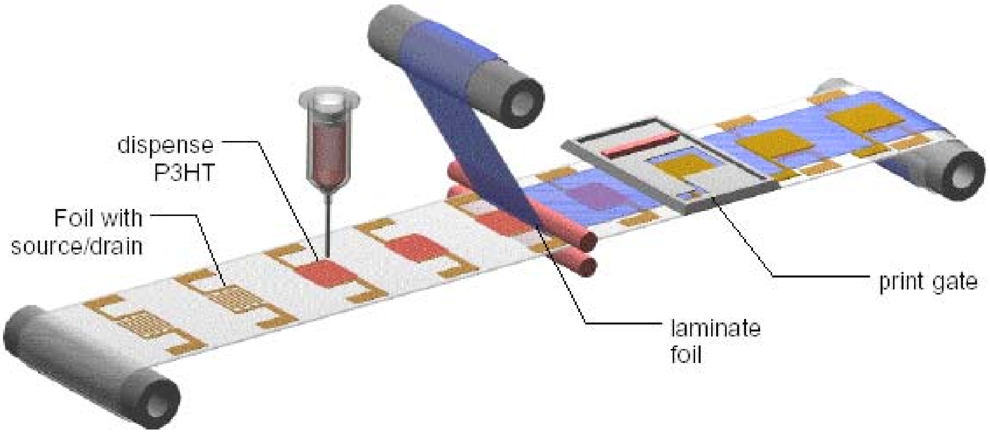

Fig.3. Reel-to-reel processing of Polymer Transistor

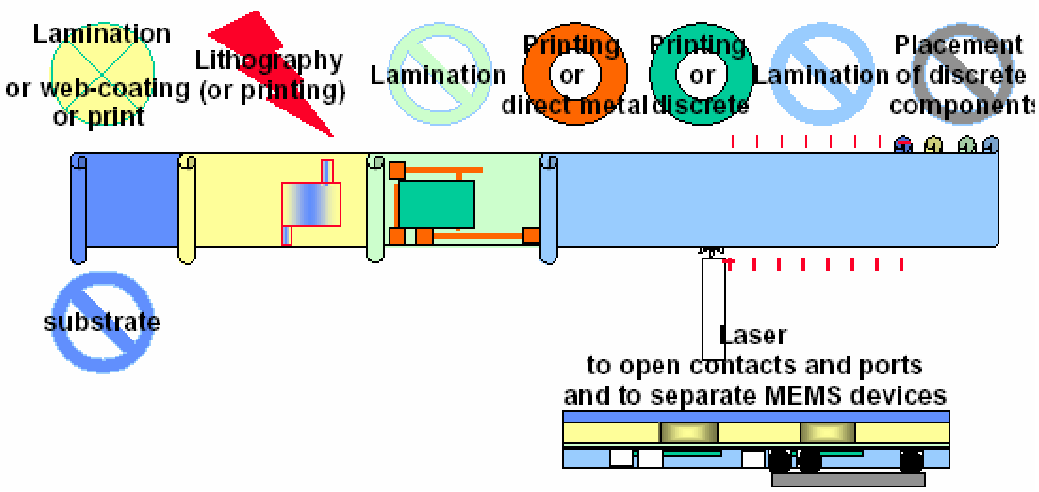

Fig. 4. Reel-to-reel processing of low-cost MEMS

It is assumed, that in the first stage of R2R production of flexible electronics not all devices can be on-line formed. Flexible smart labels, for example, include a battery and small chips which have to be interconnected. The Complex

Flexible System Assembly in IZM Center includes the module for this performing (Figure 2). Anisotropic or isotropic conductive adhesives as well as non conductive adhesives can be used in the assembly process. In case of isotropic electrically conductive adhesives, the success of flip-chip technology will be guaranteed only with quick jet printing of very small bumps. Microdrop [9] has proposed the dispenser for printing with the nozzle of 30µm. The system needs an adhesive with viscosity of adhesives from 0.4 to 20mPas and nano-size filler. There are works which have presented the first results of adhesive formulations containing silver nano powder for DC [10] and microwave applications [11].

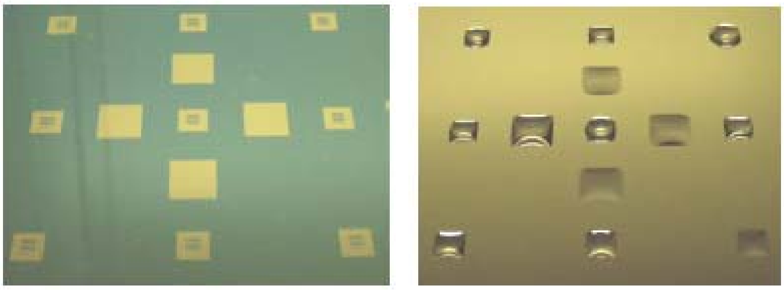

Fig. 5. Self assembly systems - assembly pattern on silicon by hydrophilization; layout for hydrophilization *(left)* and plasma hydrophilized Si-chip wetted with water *(right)*

It is predicted that assembly cost could be reduced by self assembly system components. IZM in their R2R line propose an application of hydrogen bridges to assemble complementary system components by DNA pairs or other mono molecular pairs, hydrophilization of Si-chip surface (Figure 5) and other phenomenon.

6. Key applications scenarios

Key applications scenarios for the possible applications of polymer electronics devices and systems foresee its significant progress in the decade. The following individual systems application are predicted:

Displays:

TFT: 8 ÷ 10 years?, low cost (flexible): 2 ÷ 5 years, POP low cost polymer (reflective): now ÷ 1 year, monochrome SM: now.

ICs & Transponder:

labels for broadband wireless communication: 8 ÷ 10 years, tags for security/brand mark protection: 2 ÷ 5 years, low functional special purpose IC: 2 ÷ 5 years.

Embedded Sensors, Actuators, MEMS:

embedded MEMS: 2 ÷ 10 years?, life-science disposables: 2 ÷ 5 years, low functional special purpose system: 2 ÷ 5 years, 3D games gifts, gimmicks & toys: now ÷ 5 years.

Batteries and integrated energy systems for mobiles:

Photovoltaic cells: 3 ÷ 10 years? depending on efficiency, piezo foils: now ÷ 5 years, polymer batteries: now ÷ 5 years.

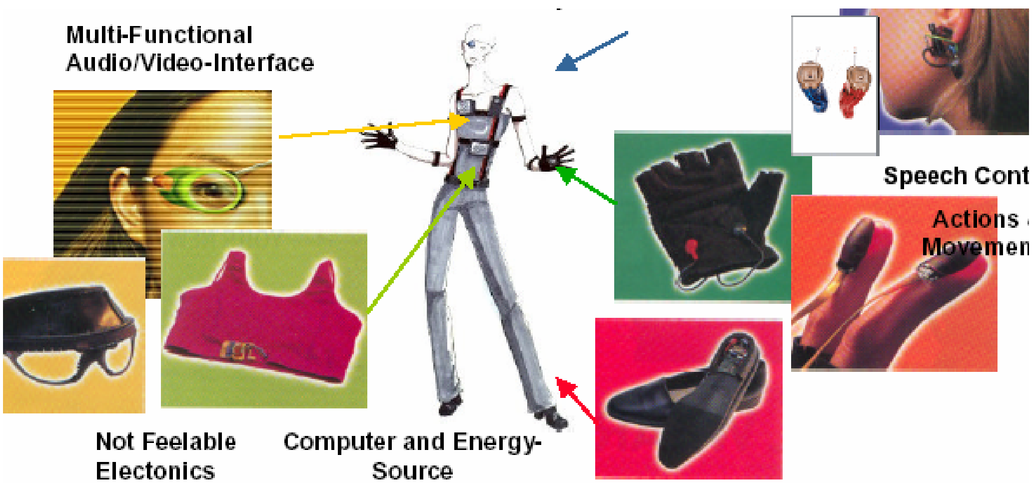

Fig. 6. Wearable ultra-micro-computers

Probably in the future we will use Wearable Ultra Micro Computers (Figure 6) equipped with computer and energy source, not feelable electronics, multi functional audio/video interface, detectors of movement and many other sensors. All of them made in polytronic technologies.

Polytronics may be one technology besides other for future electronic systems. It will provide a cheap method for the fabrication of simple low-cost electronic, but in most cases these circuits have to be integrated in a system, which may combine different technologies (e.g. a polymer display must be integrated with pixel drivers, processor, power supply, memory I/O-circuits etc.) or different functions (e.g. electronics, sensors and actuators are combined for an intelligent medical plaster). Development task of the system integration is to tune the different circuits or subsystems to each other, so that the whole system can operate. Polymer circuits will cause effects on peripheral devices, which must be identified and adopted.

7. Conclusion

The age of polymer electronic has begun. It is not primarily a replacement for existing electronic technologies, but opens up the prospect of completely new applications that combine the features of transistor, LED, detector and interconnect devices with the freedom of design, flexibility and low cost of plastics. In the scope of these new findings it seems possible that polytronics may solve present and coming problems and add new functionality to microelectronic circuits and systems. Polytronics creates a new and very promising technological area with new applications and products. Research on polymer electronics is not a fancy of well equipped laboratories which have too much time and money. Polytronics may be one technology besides other for future electronic systems.

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