Polymer Photonic Technologies for Optical Communications

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ABSTRACT

The impact of photonics in telecommunications is indisputably massive; however it relies on efficient cost reduction which is in turn only possible if significant cost savings are made at all steps in the development of the photonic device from the material to packaging. The PHOTOPOLIS consortium has identified polymer technology as the ideal solution for producing low-cost devices. The paper aims to discuss the status of polymer photonic components and subsystems able to generate, transmit and manage optical information in a cost effective manner.

Keywords: polymer photonics, optical communications, polymer devices.

1. INTRODUCTION

The impact of photonics in telecommunications is indisputable; the huge bandwidth of the optical fibre and photonic devices has revolutionized technological culture with social implications. However the true potential of photonic telecommunications technology is not as yet unravelled. This will only happen when photonic technology physically reaches the end-user. Large research and commercial efforts are aiming towards this direction through technologies such as Fiber-To-The-Home (FTTH). For the development of FTTH and access networks the key optimization factor is the cost of devices. Similarly, in order to sustain revenue growth, network operators have to turn to cost reduction and hence OPEX and CAPEX reduction in all networks segments.

Efficient cost reduction is only possible if significant cost savings are made at all steps in the development of the photonic device from the material to packaging. The PHOTOPOLIS consortium identifies polymer technology as a strong candidate technology for producing low-cost devices and unites wide research expertise in photonics science and technology, proposing the first vertical approach to explore and integrate "Polymeric photonic systems for applications in information technologies". The principal objective of the PHOTOPOLIS research initiative is the development of individual polymer photonic subsystems and the realization of low cost, all-polymeric systems for a variety of free-space and wire-link telecommunication applications. To this end PHOTOPOLIS aims at the demonstration of functional polymeric photonic subsystems and structures and their implementation in existing optical communications systems.

The present contribution discusses polymer photonics for optical communications in terms of i) polymeric material ii) fabrication methods iii) passive and iv)active polymer photonic devices. Based on this the PHOTOPOLIS approach will be presented.

2. PHOTONIC POLYMER MATERIALS

The available synthesis and flexible processing together with the superior optical properties of photonic polymers make them ideal for application in personal, local area and medium-haul optical networks [1]. Indeed, the optical loss of advanced polymers (≈ 0.1 dB/cm) is comparable to that of SiO_2. In addition, their optical characteristics can be tuned to satisfy various application requirements, and more specifically to develop integrated processing devices by controlling the geometry and tailoring the refractive index. The plethora of photonic polymer materials has been presented elsewhere [2]. Indicatively we mention that various polymers (acrylates, polymides, polysiloxanes, PMMA *etc.*) have been demonstrated for telecommunications applications with tailored optical properties (loss, refractive index).

978-1-4799-0683-3/13/$31.00 ©2013 IEEE

A most significant aspect, which is relevant to PHOTOPOLIS relates to optical nonlinearities of polymer materials. High nonlinear third order susceptibility $\chi^{(3)}$ has been reported in a large number of organic and polymeric materials such as derivatives of benzothiazole, diazole, phthalocyanine, porphyrin (see e.g. [3]). The $\chi^{(3)}$ nonlinearity is an important ingredient leading to signal optical processing applications, including optical switching, wavelength conversion, pulse reshaping and regeneration and other functionalities.
The main approaches to achieve high $\chi^{(3)}$ relate to the a) extension of π-electron conjugation of the organic chromophore, b) development of copolymers and molecule complexes (push-pull type molecules) to increase polarizability and dipole moment by simultaneous control of their organization and orientation in space, owing to packing of molecules in the solid state that affects the nonlinear properties and c) the introduction of highly polarized electrons from metals to the chromophores conjugated system.

3. FABRICATION METHODS

Polymeric waveguides and photonic structures can be constructed in various ways, ranging from conventional photolithography to electron beam lithography (e-beam lithography), soft lithography and molding, and laser micromachining [2]. The choice of the suitable technique depends on i) the polymeric material ii) the application requirements iii) the cost and iv) fabrication yield.

Photolithography is the most commonly used method for the processing of polymers. This is, however, a multi-step processing method involving deposition of a photosensitive resin on the material by spin-coating, exposure to UV radiation through a pattern mask, and application of wet and/or dry etching, including Reactive Ion Etching (RIE) [4],[5] to transfer the pattern. In order to fabricate polymeric photonic structures with low loss scattering via photolithography, more sophisticated dry etching techniques have been employed, such as inductively coupled plasma source (ICP) [3]. Another form of photolithography relates to photobleaching [6],[7], in which polymers are modified so that the etching step is circumvented. Main impediments of conventional photolithography relate to i) increased prototyping costs ii) multi-step processing nature, by use of multiple lithographic masks and exposures, iii) the use of photoresists, which can be restrictive in terms of process materials compatibility.

Direct Laser Writing and Patterning techniques (Laser Micro-Processing), on the other hand, do not require the use of masks and separate etching procedures, thus enabling rapid prototyping and waveguide fabrication as it is usually performed by use of deep UV lasers [8], [9]. Direct patterning can also be realized by e-beam [10], [11] producing very fine features down to the nanometer scale, though such high accuracy achieved does not corroborate mass production. Nevertheless, fabrication by use of UV-laser patterning based on laser ablation processes is a fast, simple and cost effective technique, exhibiting significant advantages. The method is limited by diffraction and optics performance to the micron size spot.

An additional very attractive method mastered by the partners is Soft Nano-imprint Lithography, in which the desired shape is patterned on a mold for subsequent transfer to the polymer surface. Variations of this technique for polymer materials include embossing [12], replica molding [13], nano-imprinting [14], micro-contact printing (μCP) [15], and UV nano-imprint lithography [16].

4. POLYMER PHOTONIC STRUCTURES

Polymeric photonic structures for telecommunications applications include passive optical elements like unimodal splitters, couplers, routers, filters, switches and active structures such as lasers, Organic Light Emitting Diodes (OLEDs) and Organic Photodiodes (OPD). Passive optical elements are differentiated here in the sense that no current is used to achieve the desired functionality, i.e. all optical switching is achieved by optically controlling the nonlinear phase of the device.

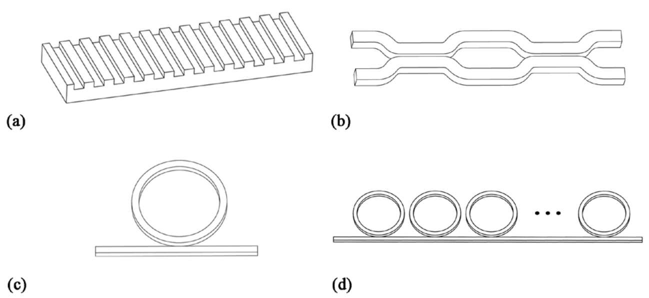

Figure 1. Popular passive photonic structures: a) diffractive grating and feedback structures, b) Mach-Zehnder interferometers, c) micro-ring cavities, d) coupled ring resonator waveguiding structures.

Passive structures are realized in various waveguide configurations including Bragg grating structures, Mach-Zehnder interferometers and micro-ring cavities and coupled resonator optical waveguides to name a few, as schematically depicted in Fig. 1. Micro-ring resonators are high-Q cavities implementing a wide range of functionalities both in the linear and the non-linear regime. They can be fabricated on all photonic platforms (polymers, III-V semiconductors, $LiNbO_3$ or glass [17-20]. In this context, PHOTOPOLIS brings the multi-functionality of micro-rings and the low cost of polymer optical materials into a single device. Even though such a combination is found in literature as relating to filters [21], switches [22] lasers [23], Mach-Zehnder modulators [24] and sensors [25], the PHOTOPOLIS approach differentiates significantly in terms of: i) the nature of PHOTOPOLIS active polymer materials offering enhanced nonlinearities ii) the physical mechanisms exploiting the $\chi^{(3)}$ nonlinear optical functions, instead of the well-studied thermo-optic and electro-optic effects and (iii) the novel integration methods towards the implementation of advanced devices. As an example, all optical switching in those passive devices is achieved by optically controlling the properties of the device. PHOTOPOLIS adopts a bottom-up approach towards applications, aiming at determining the limits of this all-optical polymeric technology in optical communications.

Active structures, such as organic light emitting diodes (Organic Light Emitting Diodes, OLEDs) have recently attracted considerable attention for flat screen displays and lighting applications [26-27]. The structure of an OLED consists of a transparent glass or plastic substrate, on which one or more organic semiconductor thin films are deposited as a p-type for hole injection and a n-type for electron injection between two electrodes, of the anode and cathode shown in Fig. 2. By applying an external electric field the injected carriers are transported and recombining emits visible light at the wavelength determined by the energy gap of the semiconductor emitters.

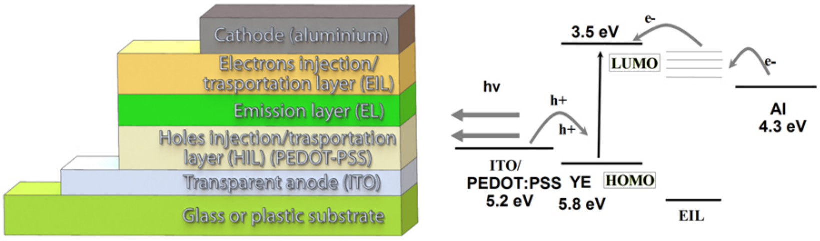

Figure 2. Structure of an OLED depicting the various layers and corresponding energy diagram.

OLEDs have significant advantages as they are low cost, lighter and thinner than their inorganic LED counterparts. OLEDs can be designed with a transient rise and fall time less than 100ns which makes them useful for applications requiring bandwidth of the order of several tenths of MHz [28]. Sophisticated modulation formats such as discrete multitone (DMT) can be used to provide gigabit-per-second connections by compensating the frequency characteristic of the device.. Optical links using OLEDs [29] have already been demonstrated at lower data rates. PHOTOPOLIS proposes the investigation and demonstration of OLED-based free space communication systems, as well as conventional wireline systems. Organic Photodiodes (OPDs) have also been demonstrated [28]. Their technology is similar to OLEDs.

5. NEW PROSPECTS FOR POLYMER PHOTONIC RESEARCH: THE PHOTOPOLIS APPROACH

The PHOTOPOLIS specific targets and respective progress beyond the state-of-the-art relate to:

i) Polymers with enhanced non-linearities tailored to telecom application requirements. In the context of PHOTOPOLIS, novel materials with supramolecular structure and enhanced nonlinearities will be synthesized. These materials will be based on boron bipyrromethene (BODIPY).

ii) Advanced passive photonic structures with emphasis on micro-ring resonators. PHOTOPOLIS passive structures combine polymer materials with enhanced nonlinearities to form complex microring resonator based photonic devices with characteristics tailored to the application requirements.

iii) Active emitter and detector devices OLEDs and OPD. PHOTOPOLIS will fabricate OLED and OPDs for telecom applications with modulation frequencies over 100 MHz

iv) New applications of photonic polymers with emphasis to CWDM systems. In particular PHOTOPOLIS RGB-OLED will be applied in CWDM systems and will be further optimized by use of advanced modulation formats for bit-rate enhancement such as discrete multi-tone and multilevel modulation.

ACKNOWLEDGEMENTS

This research has been co-financed by the European Union (European Social Fund - ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) Research Funding Program: THALES. Investing in knowledge society through the European Social Fund, grant number MIS 377358.

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