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NEWS AND VIEWS

Ultralow-power polymer electro–optic integrated modulators

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On-chip integration of electronics and photonics have attracted substantial amount of interest in recent decades. Major obstacles to the realization of this integration are size mismatch between electronic and photonic circuits, as well as issues with ever-increasing requirements for energy efficiency, bandwidth, optical loss, and drive voltage. Another important issue is the absence of photonic materials that make such integration commercially possible in foundry-compatible processes. Future integration involves combination of various materials and platforms. During the last decade there has been an increasing interest in exploiting various photonic platforms to overcome these obstacles. Integration of silicon photonics[1–3] with technologies such as plasmonics[4–6], photonic crystal architectures[7], and hybrid materials[8] have been widely pursued for photonic integration.

One of the main components of integrated communication systems is optical modulator which is used to modulate characteristics of a light beam propagating in an optical waveguide. In general, applying an electric field to a material may change its real and imaginary refractive indices. A change in the real part of the refractive index with an applied electric field is known as electro-refraction, while a change in the imaginary part of the refractive index is called electro-absorption effect. The primary electric field effect that are traditionally used in semiconductor materials for causing either electro-absorption or electro- refraction are Pockel's, Kerr's, and the Franz–Keldysh's effect[9]. It has been shown that these effects are weak in all-silicon platforms at the telecommunications wavelengths (1.3 and 1.55 μm). Thus, alternative methods are required in order to achieve efficient modulation in silicon. The most common method so far has been to exploit the plasma dispersion effect, in which the concentration of free charges in silicon changes the real and imaginary parts of the refractive index[9]. Manipulation of the charge population interacting with the propagating light is achievable through mechanisms such as carrier injection, accumulation or depletion. Silicon optical modulators can be directly formed on SOI wafers using CMOS-compatible foundry processing, but at the cost of limited extinction ratios[10, 11] and linearity[12].

Due to the low efficiency of the silicon modulators, alternative modulation mechanisms have been investigated in other materials which are compatible with silicon technology, such as germanium. However, this requires introduction of a second material in silicon platform, which complicates device designs.

Other modulation options are available by creating hybrid photonic circuits using crystalline materials or organic polymers. Lithium niobate (LN) electrooptic modulators (EOMs) have been the standard choice for long-haul communication and are widely available as commercial off-the-shelf products[13, 14].

On the other hand, low cost, simplicity of fabrication, and large-scale integration capabilities of low optical loss organic materials (polymers) make them an attractive choice for integrated photonic applications. EO polymers consisting of a polymeric matrix doped with organic nonlinear chromophores have enabled r_{33} (EO coefficient) of 3 to 10 times larger than that of LN which results in wide-RF-bandwidth and low power optical modulators. Compact on-chip modulators (up to a few millimeters long) have been made possible by hybrid integration of EO polymers onto the silicon platform. One example can be seen in Fig. 1(b).

Theoretically, devices with organic EO materials can achieve terahertz modulation bandwidths by exploiting the ultrafast response times of organic chromophores to the applied electric fields[15]. In order to realize efficient EO activity in devices with organic materials, electric field poling is performed to align the constituent dipolar chromophores with the applied radio frequency and optical fields. The resultant hybrid silicon-organic modulators can potentially combine the advantages of large-scale silicon photonic integration (Fig.1(a)) with the ultra-high EO coefficients obtained by poled EO polymers. As an example, one widely used polymer is shown in Fig. 1(c) with an r_{33} 3 times larger than that of LN.

One of the main figures of merit for EOMs is the half-wave voltage–length product ($V_{\pi}L$). It has been advanced from ⩾10 V·cm for conventional LN modulators[13] to < 40 V·μm for hybrid polymer modulators[16, 17]. Reductions in $V_{\pi}L$ have resulted in more compact devices. Moreover, low loss polymer EOMs with energy efficiency in the order of femtojoule/bit levels, ⩾170 GHz bandwidths, and ⩾25 dB extinction ratios, have been demonstrated[16–20].

Recently, 100 Gbit/s on-eff keying has been reported in a 1.1-mm-long silicon-organic EOM with a half-wave voltage of 0.9 V, and a record-low value of 98 fJ/bit for energy consumption[21]. Promising reports along with theoretical studies suggest that device performance can be substantially improved in the future. Achieving in-device EO coefficients of >1000 pm/V and $V_{\pi}L$ values of < 10 V·μm are expected as near-term objectives for future research.

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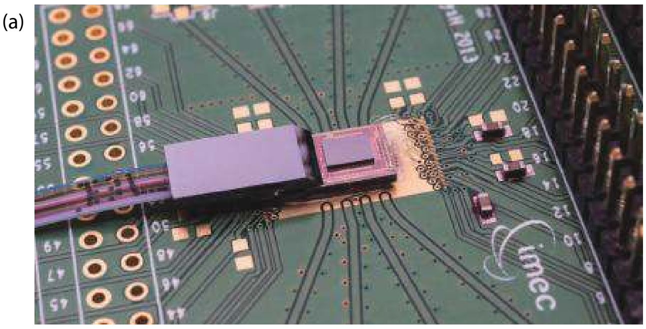
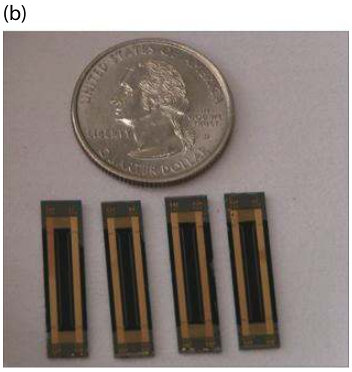


Intergrated silicon photonics [www.imec-int.con]



Size comparison for in tegrated
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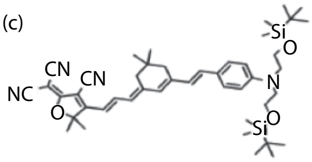

CLD-1, one of the widely used polymers with large
electro–opitc coefficient [RSC Adv., 2015, 5 15784]

Fig. 1. (a) Integrated silicon photonics[22]. (b) Size comparison for integrated electro-optic polymer modulators[23]. (c) CLD-1, one of the widely used polymers with large electro-optic coefficient[24].

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