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NLM

HLD

Organic Non-linear Optical (NLO)
Material with High Electro-optic Effects

Up to 10X the performance of lithium niobate

HLD is a high performing organic material with superior thermal stability suitable for commercial applications.

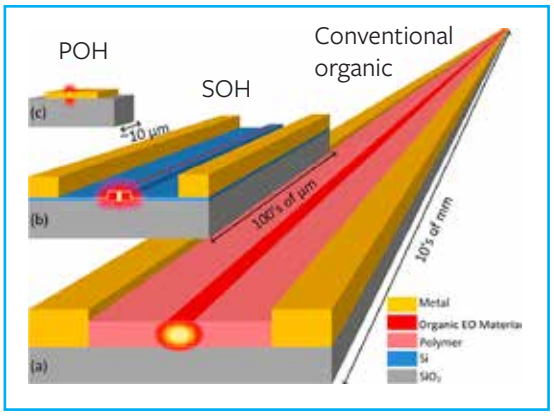
Electro-optic (EO) modulators exhibiting the Pockels effect are typically used when converting electrical signals to optical signals within optical telecommunication networks. Hybrid EO technology comprised of organic materials and silicon device architecture leverage the large EO response of organic chromophores plus small device sizes enabled by SOI fabrication. Organic EO materials have achieved record bandwidths and switching speeds when implemented in hybrid devices, as well as energy efficiencies on the order of 100 aJ/bit.

Applications

Telecommunications
Optical Networking
Optical Computing
RF Photonics
Optica Neural Networks
Antennas
Terahertz radiation sources/detectors

Device types

Plasmonic-organic hybrid (POH) devices
Silicon-organic hybrid (SOH) devices
Phase, Mach-Zehnder, and IQ modulators
Frequency combs and beam steering
Optical frequency mixers (antennas)



Advantages of NLM's HLD

- Higher electro-optic activity compared to incumbent inorganic materials like lithium niobate ($LiNbO_3$)
- Pockels effect yields linear response w/o chirping
- Solution processable in an array of solvents
- Thermally stable*, with little drop in r_{33} after 500 hours at 85 °C
- Ultrafast response and large bandwidths (> 500 GHz demonstrated for related materials)
- Small device footprints possible (<10 μm^2)
- Crosslinking technology to preserve acentric order for locked-in, stable performance
- Glass transition temperature (T_g) tunable

Physical Properties

- Electro-optic coefficient (r33) @ 1310nm:
  - Up to 460 pm/V without crosslinking
  - Up to 290 pm/V with crosslinking (in a parallel plate configuration)
- Refractive index at 1550 nm (from VASE) = 1.83 - 1.85
- Thin film absorption maximum (λmax): 782 nm
- Hyperpolarizability (β) in $CHCl_3$: 2120 x 10^{-30} esu
- Thermal stability: > 500 hours at 85 °C
- T_d > 250 °C
- Poling temperature: 101 – 105 °C
- T_g (pre-crosslinking): 72-75 °C
- T_g (post-crosslinking): 139 – 175 °C
- Peak crosslinking temperature: 160 °C

Processing

Organic materials are highly desired for their ease of processing. These materials can be prepared neat as a thin film or with a polymer host system by dissolving in a variety of compatible solvents.

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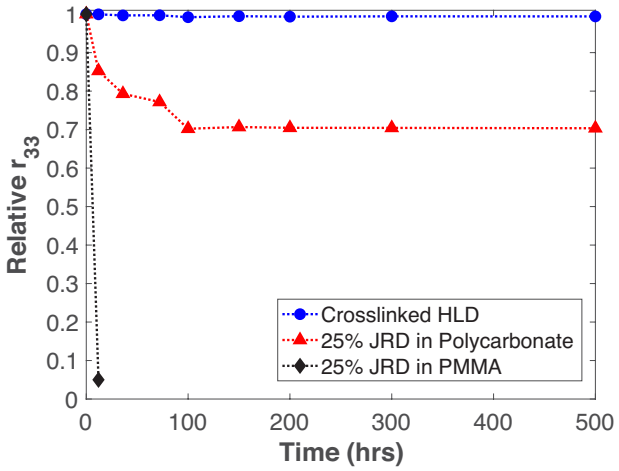
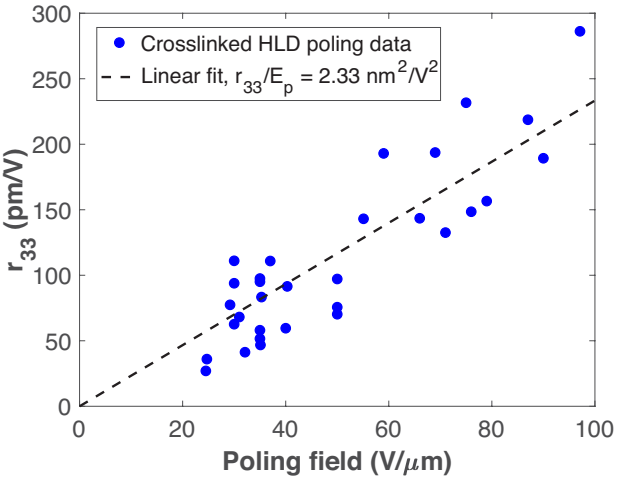
Performance Stable >500 hours at 85 °C



Electro-optic Activity with Crosslinking

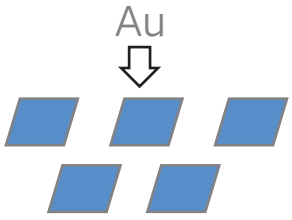


Up to 300 pm/V performance as a neat material (no polymer host)

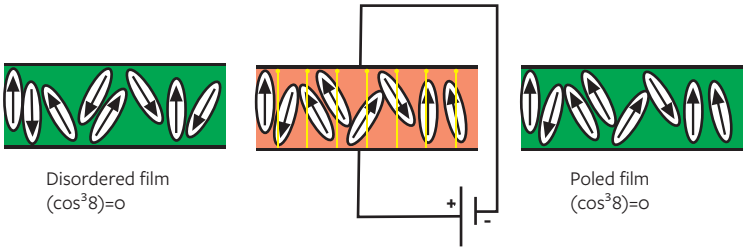
Processing Flow

1. Dissolve chromophore powder in solution
2. Apply solution to substrate
3. Perform spin- or blade-coating to create thin film
4. Anneal films at elevated temperature specified

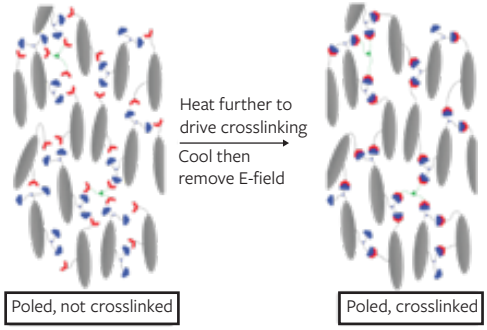
5. Prepare remaining device configuration with electrical contacts



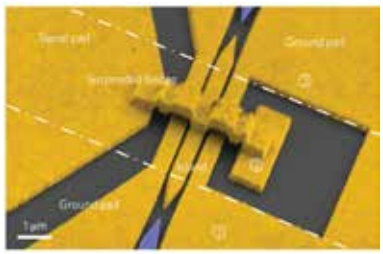
6. Perform electric field poling process to orient chromophore molecules



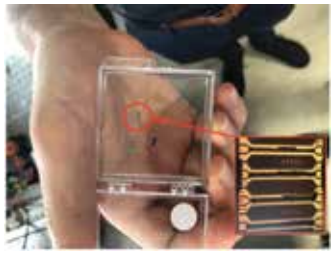
7. Perform additional crosslinking step for enhanced thermal stability (optional)



8. Measure EO activity use in desired application



W. Heni et al. ACS Photonics 2017, 4, 1576-1590



Prototype SOH devices using JRD1 developed at Karlsruhe Institute of Technology

Next Generation Materials for Photonics

Comparison of Electro-Optic Materials Platforms

Materials Platform	Silicon Photonics	III-V (e.g. InP)	TFLN (Lithium Niobate)	TFBT (Barium Titanate)	NLM Hybrid OEO
Mechanism	Semiconductor junction	Multiple mechanisms	Pockels effect	Pockels effect	Pockels effect
Light/RF overlap	Semiconductor junction	Good	Poor	Very poor	Good
Size (at 1V drive)	5 mm	5 mm	20 mm	0.15 mm	0.05 mm
Best demonstrated 3 dB bandwidth (GHz)	50	80	80	15	500+
SOI CMOS fabrication?	Yes	No	No	Partial	Yes
Post-CMOS complexity?	Low	Moderate	High	High	Moderate

NLM's Services

- Organic electro-optic materials for sale and licensing
- Consulting on materials integration and process development
- Research and development of novel nonlinear materials (second order $\chi^{(2)}$, third order $\chi^{(3)}$), including theory-aided development of novel materials
- Joint development with device manufacturers and fabrication facilities

Additional References

1. W. Heni et al. ACS Photonics 2017, 4, 1576-1590
2. C. Haffner et al., Proceedings of the IEEE 2016, 104, 2362-2379
3. C. Kieninger et al., Optica 2018, 5, 739-748.
4. C. Haffner et al., Nature Photonics 2015, 9, 525-528.
5. W. Jin et al., Applied Physics Letters 2014, 104, 243304

About Nonlinear Materials Corporation

NLM is a full service company designing, synthesizing, and producing ultra-high performance materials with a nonlinear response for photonics applications. NLM develops, sells, and licenses materials. Please contact us with any questions.

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