NonlinearMaterialsCorporation

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

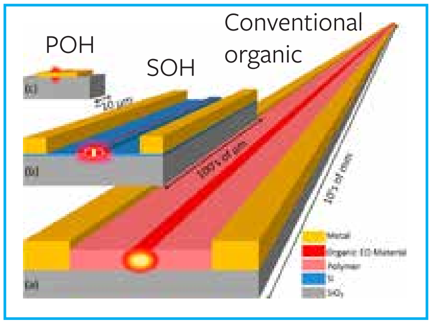
Telecommunications
Optical Networking
Optical Computing
RF Photonics
Optica Neural Networks
Antennas
Terahertz radiation sources/detectors

### 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)

### 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.




### Advantages of NLM's HLD

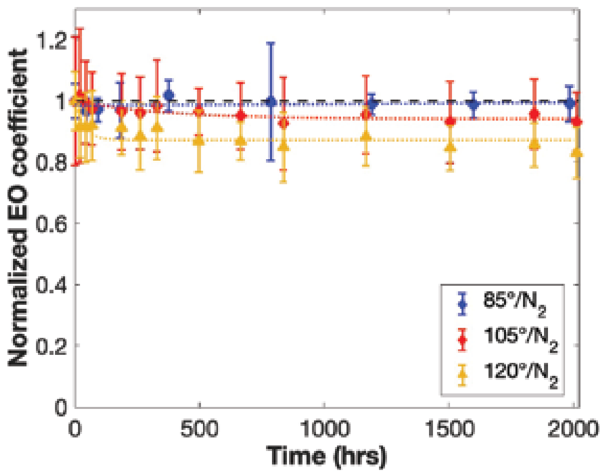
HLD materials will improve your device performance and stability and make way for future innovations.

- Crosslinking technology to preserve acentric order for locked-in, stable performance.
- The thermoset plastic exhibits exemplary thermal stability, with no drop in r33 after 2,000 hours of shelf storage at 85 °C in an inert environment. Inert shelf storage at higher temperatures, up to 120 ˚C, produces only a small initial "burn-in" (5-20%) followed by stable performance. Device operation has been demonstrated up to 140 °C for brief periods, enabling use in demanding thermal environments.
- Crosslinked material is resistant to many common solvents. This resistance allows other processing steps - such as depositing other materials, photolithography, cleaning, etching, encapsulation, etc. - to happen without dissolving the EO material.

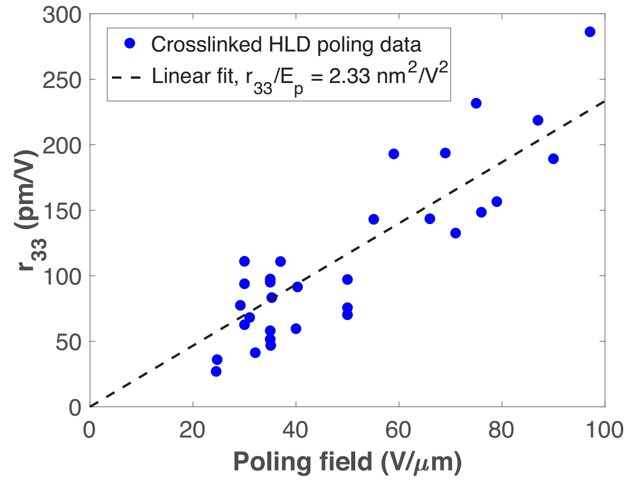
### Physical Properties

- Electro-optic coefficient (r33) at 1310 nm:
  - Up to 460 pm/V without crosslinking (in a parallel plate configuration)
  - Up to 290 pm/V with crosslinking (in a parallel plate configuration)
- Refractive index at 1550 nm (from VASE) before crosslinking = 1.88 – 1.89
- Refractive index at 1550 nm (from VASE) after crosslinking = 1.83 – 1.85
- Absorption (k) at 1550 nm (from VASE) before crosslinking < 0.0001
- Absorption (k) at 1550 nm (from VASE) after crosslinking < 0.0002
- Thermal stability: > 2000 hours at 120 °C (long-term), up to 140 °C (short-term)
- Td > 250 °C
- HLD1 Tg (before-crosslinking): 75-90 °C
- HLD2 Tg (before-crosslinking): 72-80 °C
- Poling temperature: 95 °C (after pre-crosslink)
- Crosslinking temperature range: 105-160 °C
- Tg = ~155-165 °C and = 175 °C under optimal conditions
- Thin film absorption maximum (λmax): 782 nm
- Hyperpolarizability (β) in CHCl3: 2120 ± 50 x 10-30 esu at 1300 nm

## Performance Stable > 2000 hours at > 85 °C



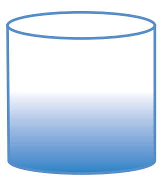

## Electro-optic Activity with Crosslinking

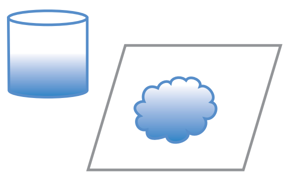


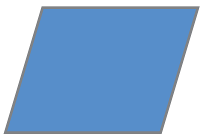

**Up to 300 pm/V performance as a neat material** (no polymer host)

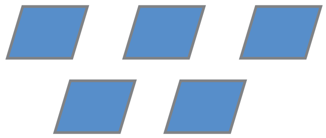
## Processing Flow

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

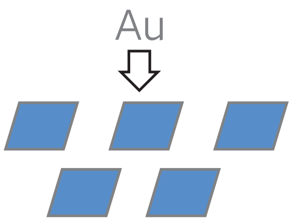


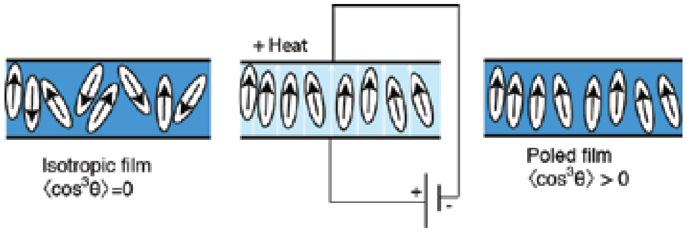




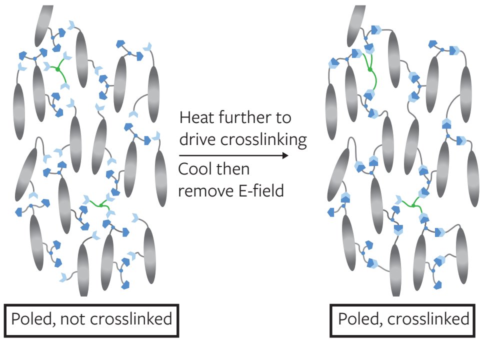


5. Prepare remaining device configuration with electrical contacts
6. Perform electric field poling process to orient chromophore molecules

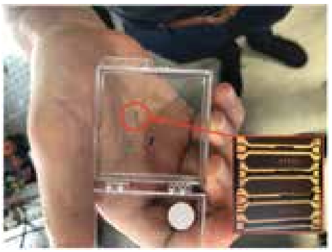



7. Perform additional crosslinking step for enhanced thermal stability (optional)
8. Measure EO activity use in desired application




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



Prototype SOH devices using JRD1 developed at Karlsruhe Institute of Technology

# 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 including theory-aided development of novel materials
- Joint development with device manufacturers and fabrication facilities

## Additional References


1. H. Xu et al., Chemistry of Materials 2020, 32, 1408-1421
2. L. Johnson et al., Proc. SPIE 11812 2021
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4. C. Haffner et al., Proceedings of the IEEE 2016, 104, 2362-2379
5. C. Kieninger et al., Optica 2018, 5, 739-748.
6. C. Haffner et al., Nature Photonics 2015, 9, 525-528.
7. 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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*Next Generation Materials for Photonics*


www.nonlinearmaterials.com
2212 Queen Anne Ave North, Box #324
Seattle WA, 98109, USA
+1-206-715-7718
contact@nonlinearmaterials.com