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**Integrated Instrumentation for Plastic Laser Materials Development**

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## 1. Introduction

There is a growing interest in utilizing conjugated polymers as electroluminescent (EL) materials in large area flat panel display applications. They possess significant processing, mechanical, thermal, and size advantages over those made by evaporation methods. In addition, it is possible to fabricate full color displays utilizing the broad spectral range of emission colors available from semiconducting luminescent polymers and organic molecules. Many conjugated polymers are luminescent materials with a Stoke shift that separates emission sufficiently far from the absorption edge that self-absorption is minimal. Because of the large joint density of states associated with the direct  $\pi$  to  $\pi^*$  (interband) transition of these quasi-one-dimensional semiconducting polymers, the absorption coefficient ( $\alpha$ ) is large, typically  $\alpha \geq 10^5 \text{ cm}^{-1}$ . To the first order, the cross-section for stimulated emission (SE) is the same as that for absorption, so the gain length should be essentially equal to the absorption length scaled by the fraction of chromophores in the excited state. Therefore, an inverted population can be achieved by pumping the  $\pi$  to  $\pi^*$  transition; this does not simultaneously stimulate emission because the absorption and emission are spectrally separated. Thus, luminescent conjugated polymers offer promise as novel laser materials with gain lengths in the micron regime.

Interest in using these polymers as solid state laser materials was initiated by the demonstration of the optically pumped gain narrowing in dilute blends of MEH-PPV in polystyrene. Subsequently, many new polymers have been developed to show similar spectral narrowing above threshold in the solid state. Achievement of gain narrowing requires that two criteria be fulfilled: 1) The active polymer medium must exhibit SE under optical or electrical excitation; 2) some type of resonant structure must enable the emitted photons to travel a distance greater than the gain length in the excited polymer. Appropriate structures for amplified spontaneous emission (ASE) include planar waveguides with distributed feedback and microcavities.

Although the optically pumped lasing of conjugated polymers offers promise in the construction of laser diodes with such materials, sufficient carrier concentrations must be produced by electrical pumping in order to render any of these devices for practical use. Based on the threshold optical pump power for the establishment of gain, several important criteria need to be met in order to achieve electrically pumped polymer lasers: 1) develop EL materials with high quantum efficiency; 2) reach high transient current densities; 3) construct a laser diode with

a high-Q resonant cavity or improved waveguiding structures. Our approach in developing suitable materials for plastic lasers is based on: 1) design, synthesis and evaluation of suitable EL polymer systems ; 2) screening and evaluation of their stimulated emission capabilities and for their threshold of gain narrowing under optical pumping; and 3) teaming up with laser physicists (Professor Alan Heeger's group at U. C. Santa Barbara) to test the feasibility of demonstrating electrically pumped lasing.

Although different groups are developing the basic luminescent molecules, polymeric materials, processes, and devices, they measure and report their results based on different specific and individual tests. Due to the different test procedures and measurement methods, it is difficult to make comparisons between the materials. Thus, selecting the most promising development path becomes difficult. To speed up the tedious selection process, it is highly desirable to have an integrated instrumentation that provides the necessary information such as charge mobility, brightness, photo- and electroluminescence, current-electric field characteristics, and thresholds of optically pumped lasing, in a short time span.

## **2. Objective**

The objective of this DURIP program is to develop an integrated instrumentation package that combines the capability of performing the measurements of charge mobility, conductivity, photo- and electro-luminescence emission spectra, luminous efficiencies, as well as the thresholds of optically pumped lasing. By integrating these testing functions together, it will provide a very efficient mechanism to evaluate potential polymer systems for the fabrication of laser diode devices.

## **3. Impact to the new research programs on LED/Laser materials at Northeastern University**

The integrated instrumentation has greatly enhanced the quality and capability of the new conjugated materials research at Northeastern University (NU) to evaluate suitable LED/laser material system properties. The new facility established by Professor Alex Jen possesses the capability of synthesizing and characterizing novel conjugated polymers. This integrated instrumentation has helped to guide the synthetic effort to fine-tune the properties of molecular structures and establish desirable material system properties of light-emitting polymers, and thus, directly impact the fabrication of highly efficient EL/lasing devices. Seventeen light-emitting

polymers related papers have been published in the refereed journals based on the characterization results derived from this set-up. In addition, this facility has provided very useful services to researcher (Professor Timothy Swager-MIT, Professor Lin Pu-U. of Virginia, Professor Larry Dalton-U. of Washington) that are supported by DoD's funding agency. The capability of this integrated instrumentation includes a Coherent Ti:Sapphire femto-second pulse laser system, a Jobin Yvon monochromator and CCD detector, a HP 500 MHz oscilloscope, and an optical table breadboard and isolating support systems.

#### **4. Interface between the instrumentation and the existing facility for electro-optic (E-O) and light-emitting materials research at Northeastern University**

This integrated instrumentation interfaces very well with the existing E-O and LED materials research facility at Northeastern University (NU) to provide strong capability to evaluate organic photonic/opto-electronic material properties. One of the new research program proposed by both professors Alex Jen aims at demonstrating an integrated all polymer LED/E-O device by using organic conjugated polymers as both a light source (plastic laser) and a photodetector, and using NLO polymer channel waveguides as an E-O switching device. This instrumentation greatly enhances the capability of quickly developing/screening both LED and E-O materials systems to ensure the greatest chance of success. In the area of polymer characterization, the facility at NU is equipped with the instruments such as TGA and DSC for thermal analysis; GPC and HPLC for polymer molecular weight measurement; and Dektak instrument for measuring thin film thickness. In addition, FT-IR and UV-Vis-Near IR spectrometer were used to determine the thermal stability of the E-O polymer thin films. In the areas of optical and electrical characterization, the micromanipulator device could be used to cure (up to 400 °C) and pole NLO thin films and channel waveguides; Metricon prism coupler could measure refractive index, optical loss, and thickness of polymer thin films; lock-in amplifier and the associated electronic system could measure optical and electro-optic signal generated by LED/E-O materials. This integrated instrumentation will help to bridge between the effort of evaluating E-O and LED polymeric material system properties, and thus, directly impact the fabrication of all polymer laser devices.

#### **5. Research training of students**

The highly interdisciplinary nature of the program to develop high performance light-emitting materials for LED/laser device applications, the outstanding faculty and institutions involved, and connections with high technology device companies and DoD laboratories ensure a rich educational environment for the graduate students, postdoctors, and undergraduate

students involved. Students are active members involved in closely integrated material synthesis, characterization, and device fabrication. Students associated with this program will emerge with a unique background and complement of skills. The ability to communicate with and work with academic, government, and industrial researchers in other disciplines towards a common goal will uniquely qualify them for the technical workforce of the future.

#### 6. Papers published that acknowledge the AFOSR

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5. "Synthesis and Characterization of Polyquinolines for Light-emitting Diodes", M. S. Liu, Y. Liu, C. Urian, H. Ma and A. K-Y. Jen, J. Mater. Chem., 1999, **9(9)**, 2201.
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7. "Polyquinolines: Multifunctional Polymers for Electro-optic and Light-emitting Applications", A. K-Y. Jen and H. Ma, Mat. Res. Soc. Proc. (in press).
8. "Efficient Light-emitting Diodes Based on a Novel Binaphthalene-containing Polymer", A. K-Y. Jen, Y. Liu, Q. Hu and L. Pu, Appl. Phys. Lett. 1999, **75(24)**, 3745. "A Binaphthyl-Based Conjugated Polymer for Light-Emitting Diodes", L. Zheng, R. C. Urian, Y. Q. Liu, A. K-Y. Jen and L. Pu, Chem. Mater., 2000, **12(1)**, 13.
9. "High Performance Binaphthyl-Based Polymers for Light-Emitting Devices", L. Zheng, X. Jiang, S. Liu, and A. K-Y. Jen, J. Organometallic Chem. (in press).

10. "High Performance Blue Light-Emitting Diode Based on a Binaphthyl-Containing Polyfluorene", X. Jiang, S. Liu, H. Ma, and A. K-Y. Jen, Appl. Phys. Lett. 2000, 76(14), 1813.
11. "Tuning of Redox Behavior and Fluorescence of Cyano-containing Phenylenevinylene Oligomers and Polymers", M. S. Liu, X. Jiang, and A. K-Y. Jen, Mat. Res. Soc. Proc. 1999, xxx. (in press)
12. "1,1-Binaphthyl-Containing Polyfluorenes for Efficient Light-Emitting Diodes", S. Liu, X. Jiang, M. S. Liu, H. Ma, and A. K-Y. Jen, Mat. Res. Soc. Proc., 1999, xxxx
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14. "Organic Light-Emitting Diodes Using a in-situ thermally polymerized hole transporting layer", X. Jiang, S. Liu, M. S. Liu, H. Ma, and A. K-Y. Jen, Appl. Phys. Lett. 2000, 76(21), 2985.
15. "Triarylamine-Containing Poly(perfluorocyclobutane)s as Hole-Transporting Materials for Polymer Light-Emitting Diodes", S. Liu, X. Jiang, H. Ma, and A. K-Y. Jen, Macromolecules, 2000, 33, 3514..
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17. "Organic Electroluminescent Devices Based on Phenanthrene-Containing Europium Complex", D. Huang, X. Jiang, G. Phelan, T. Londergan, A. K-Y. Jen, and L. R. Dalton, Poly. Mater. Sci. Eng., 2000, 83, 266.

**Budget:**

Item	Model	Features	Price	Contact
Pulsed Nd: YAG Laser	Spectra-Physics GCR-100	0.85 J/pulse	85,000	Tel: 1-800-775-5273 Fax: 1-650-968-5215 Email: sales@splasers.com
Optical Parametric Oscillator (OPO)	Spetra-Physics MOPO-PO	410nm-2200nm	35,000	Tel: 1-800-775-5273 Fax: 1-650-968-5215 Email: sales@splasers.com
Oscilloscopy	Hewllet-Packard	500Mhz, 2Ch,	15,900	Tel: 1-800-452-4844

	HP54522C	2Ghz Sampling		Fax: 1-800-800-5281
Monochrometer	ISA Jobin Yvon SPEX: 500M with CCD	focal length: 0.5m resolution: 0.02nm	16,450	Tel: 1-800-438-7739 Fax: 1-732-549-9309 Email: systems@isainc.com
CCD detector	ISA Jobin Yvon SpectrumOne		20,500	Tel: 1-800-438-7739 Fax: 1-732-549-9309 Email: systems@isainc.com
Photomultiplier Tubes (PMT)	Hamamatsu	UV/Vis/NIR	500	Tel: 1-908-231-0960 Fax: 1-908-231-1539
Optical Tabletop Breadboard	Newport RG-35-4-ML		2,841	Tel: 1-800-222-6440
Overhead Table Shelf	ATS-5		1,732	<a href="http://www.newport.com">http://www.newport.com</a>
Isolating Support Systems	I-2000-428		979	
Optical Components	Newport			Tel: 1-800-222-6440 <a href="http://www.newport.com">http://www.newport.com</a>
lens	LKIT-2AR.16	Singlet Lens	1,175	
	CKIT--2AR.16	Kits	1,575	
mirrors	10QM20HM.15	Cylindrical Lens	400	
	10QM20HM.35	Nd:YAG/1064	400	
	10QM20HM.45	Nd:YAG/532	480	
	10QM20HM.75	Nd:YAG/355	480	
	10Z40+BD.1	Nd:YAG/266	137	
	10Z40+BD.2	488-694	165	
Right-angle Prism	10BR08	700-950	290	
Beamsplitter	10B20+BS.1		390	
Attenuator	FB-ND	Broadband	295	
<b>Total: 184,689</b>				