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An Organic Thin Film Laser Diode: A New and Novel Light Source

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13. ABSTRACT (Maximum 200 words)

This ONR program was focusing on the development of an entirely new diode laser, based upon electroluminescent organic thin films. During these three years, important milestones have been reached towards the demonstration of the first organic laser diode: (i) demonstration of electroluminescence from an organic channel waveguide device fabricated on glass and on Si. (ii) optical gain in excess of 10^4 cm^{-1} measured in a pure solid state conjugated polymer. (iii) fabrication of feedback structures with 0.2 μm resolution. With the synthesis of new compounds and their characterization (determination of HOMO and LUMO levels), the performance of organic light emitting devices could be continuously improved. Current devices exhibit external quantum efficiencies as high as 3 % with a stable aluminum cathode. Output light levels in excess of 45,000 cd/m^2 (500,000 cd/m^2 in pulsed regime) are measured at this stage and are getting close to the levels required to achieve gain in electrically injected structures. Finally our research efforts have led to the recent demonstration of optically pumped integrated organic laser diodes using several configurations. Simultaneously, we have developed a complete theory of optical absorption in PPV and determined the origin of photo-induced absorption in this material and other π-conjugated polymers.

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Our proposal to ONR # N000149410322 focused on the development of an entirely new diode laser, based upon electroluminescent organic thin films. During this three-year program important milestones have been reached towards the demonstration of the first organic laser diode:

- first demonstration of electroluminescence from an organic channel waveguide device fabricated on glass and on Si. Lateral confinement could be defined by either etching and filling a trench in photoresist or by changing the refractive index of the active polymer by photobleaching using UV light. Electroluminescence could be demonstrated in these waveguides and 3 dB/cm propagation loss was measured.

- optical gain in excess of 10^4 cm^{-1} has been demonstrated in a pure solid state conjugated polymer. The gain dynamics was fully characterized with picosecond resolution.

- feedback structures with 0.2 μm have been fabricated.

Our ultimate goal to demonstrate an electrically organic laser diode remains to the best of our knowledge a challenging task. However, our research efforts have initiated the recent demonstration of **optically pumped organic laser diodes**. Our advances in material development and characterization made during this program had a strong impact on the integrated laser structures that we develop currently under ONR funding. Current devices exhibit external quantum efficiencies as high as 3 % with a stable aluminum cathode. Output light levels in excess of 300,000 cd/m^2 are measured at this stage and are getting close to the levels required to achieve gain in electrically injected structures.

In addition, during our three-year program, we have completed the following tasks that have led to a gradual increase of the external quantum efficiency of our organic light emitting devices:

- fabrication of a state-of-the-art sample preparation unit for organic films under controlled atmosphere
- screening of a significant number of organic molecules for hole transport, light emitting, and electron transport layer
- synthesis of new compounds, including soluble blue-green metalloquinolates, and new electron transport quinoxaline derivatives
- determination of the HOMO and LUMO positions of luminescent and transport materials
- developed a complete theory of optical absorption in PPV and determined the origin of photo-induced absorption in this material and other π-conjugated polymers.

• Calculated polaron binding energies for various electron and hole transport materials. Demonstrated that the magnitude of the electron and hole polaron binding energies determines whether a given material is electron or hole carrier.

List of Technical Reports and Journal Articles

"Growth and Optical Characterization of Ordered Thin Films of Perylene Dyes on Au(111) and Metal Halide Single Crystal Surfaces," T. Fritz, M. Hoffman, T. Schmitz-Hübsch, R. Staub, F. Sellman, D. Schlettwein, A. Back, P.A. Lee, N. R. Armstrong, -- European Conference on Molecular Electronics, Sept. 1996

"Characterization of the Critical Energy Levels in Organic/Organic' Heterojunctions: Organic LED and Organic Photovoltaic Materials," M. L. Anderson, A. Schmidt, D. Schlettwein, G. Schnurpfeil, S. Hiller, and D. Wörhle, N. R. Armstrong, European Conference on Molecular Electronics, Sept. 1996.

"HOMO/LUMO Energies and Ionization Potentials of Thin Films of Polycyclic Organic Dyes: Organic/Organic' Heterojunctions Probed by UV-Photoelectron Spectroscopy and Visible Wavelength Spectrophotometry/Luminescence," A. Schmidt, T.J. Schuerlein, M.L. Anderson, A. Back, G. Schnurpfeil, S. Hiller, D. Schlettwein, and D. Wörhle, N. R. Armstrong, J. Phys. Chem. submitted.

"Electroluminescence in an organic polymer channel waveguide," B. Kippelen, S. E. Shaheen, M. M. Morrell, P. T. Guerreiro, P. M. Allemand and N. Peyghambarian, Conference on Lasers and Electro-Optics, Technical Digest Vol. 9, 88 (1996).

"Electronic States of Vapor Deposited Electron and Hole Transport Agents and Luminescent Materials for Light-Emitting Diodes," with A. Schmidt, M.L. Anderson, N. R. Armstrong, J. Appl. Phys. **78**, 5619 (1995).

"Substituted aluminum and zinc quinolates with blue-shifted absorbance/luminescence bands: synthesis and spectroscopic, photoluminescence and electroluminescence characterization," T. A. Hopkins, K. Meerholz, S. Shaheen, M. L. Anderson, A. Schmidt, B. Kippelen, A. B. Padias, H. K. Hall, Jr., N. Peyghambarian, and N. R. Armstrong, *Chem. Mater.* **8**, 344-351 (1996).

(Invited) *"Polymers for photorefractive and light emitting applications,"* N. Peyghambarian, B. Kippelen, K. Meerholz,* B. L. Volodin, Sandalphon, S. E. Shaheen and M. Morrell, ACS meeting New Orleans, (1996).

(Invited) *"Polymers for optoelectronic applications,"* N. Peyghambarian, Japan, MRS Symposium, May 24, Makuhari, Japan (1996).

(Invited) *"Physics and applications of novel nonlinear optical devices based on semiconductors and polymers,"* N. Peyghambarian and B. Kippelen, Industrial Science and Technology Frontier Program, 5th Symposium on Nonlinear Photonics Materials, Nov. 20, Osaka, Japan, (1996).

"Excitons in Poly(p--phenylenevinylene)", M. Chandross, S. Mazumdar, S. Jeglinski, X. Wei and Z.V. Vardeny, Physical Review B **50**, 14702 (1994).

"Stable Biexcitons in Conjugated Polymers," F. Guo, M. Chandross and S. Mazumdar, Physical Review Letters **74**, 2096 (1995).

"Optical Absorption in the Substituted Phenylene-based Conjugated Polymers: Theory and Experiment," M. Chandross, S. Mazumdar, M. Liess, P.A. Lane, Z.V. Vardeny, M. Hamaguchi and K. Yoshino, Physical Review B **55**, 1486 (1997).

"Coulomb interactions and Linear, Nonlinear and Triplet Absorptions in Poly(para-phenylenevinylene)," M. Chandross and S. Mazumdar, Physical Review B **55**, 1497 (1997).

"Determination of Ionization Potentials and Estimation of HOMO/LUMO Energies For Thin Films of Polycyclic Organic Dyes and Organic/Organic Heterojunctions," A. Schmidt, M. L. Anderson, P.A. Lee, G. Schnurpfeil, S. Hiller, D. Schlettwein, D. Whrle, and N. R. Armstrong, J. Phys. Chem, submitted.

"Characterization of the Critical Energy Levels in Organic/Organic Heterojunctions: Organic LED and Organic Photovoltaic Materials," N. R. Armstrong, invited lecture, ECME 96 (European Conference on Molecular Electronics), Leuven, Belgium (1997).

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