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RSOFT Design Group

REVIEW

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Electronic Dispersion Compensation of Propagation Impairments in High-Speed Optical Links

Recent advances in optical communication systems demonstrated that upgrades of optical networks to higher bit rates - 10 Gb/s and 40 Gb/s - require careful mitigation of inter-symbol interference (ISI) caused by propagation impairments such as chromatic, polarization mode, and modal dispersion. This is usually done by introducing *in situ* optical and electronic compensators or mitigators. Electronic dispersion compensators are potentially less expensive solution compared to the optical counterpart and have been already commercialized. Two main applications for EDC are: (a) upgrade of existing Ethernet links to 10Gbase over the legacy fibers by providing differential mode dispersion (DMD) compensation, and (b) increase the reach of long-haul and metro SONET OC-192 optical links (10 Gb/s) and/or upgrade to OC-768 (40 Gb/s) by providing PMD and chromatic dispersion compensation. IEEE is developing EDC-based standard 802.3aq (10GBase-LRM) for 10 Gigabit Ethernet, and OIF/ITU is developing EDC-based standard ITU-TFG15 for SONET OC-192 upgrade.

EDC is based on electronic filtering technology known as equalization, which is well established in digital communications (e.g. wireless, modem, disk drives). There are various equalization algorithms upon which an effective EDC implemen-

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Modeling a CMOS Pixel with FullWAVE's New Non-Uniform Mesh

Image sensor technology has been dominated by CCD sensors for many years due to excellent imaging performance using relatively simple semiconductor technology. In recent years, thanks to advances in microlithography and fabrication process control, CMOS sensor technology has become a viable alternative. CMOS sensors present several advantages such as lower power consumption, reduced system size, and close integration with logic and signal processing systems. These benefits allow electronic manufacturers to better meet market needs such compact and low-power sensors for digital cameras and mobile phones.

In order to correctly model the efficiency of a CMOS pixel geometry, it is important to determine amount of optical power absorbed into the silicon substrate through an optical simulation. This information can then be fed to an electrical simulator to model the pixel charge generation. RSoft's *FullWAVE*, which is based on the Finite-Difference Time-Domain (FDTD) algorithm, is well-suited for such an optical simulation: it models the time

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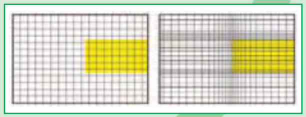
Non-Uniform Mesh with FullWAVE

RSoft has introduced a non-uniform mesh feature for it's *FullWAVE* software. A non-uniform mesh allows the use of a finer mesh at material interfaces, especially metals, where fields tend to change rapidly and a courser mesh in bulk regions, resulting in less grid points and therefore shorter simulation times. Without this feature, the mesh would have to be uniform and set to the smallest value needed within the simulation domain in order to get similar accuracy.



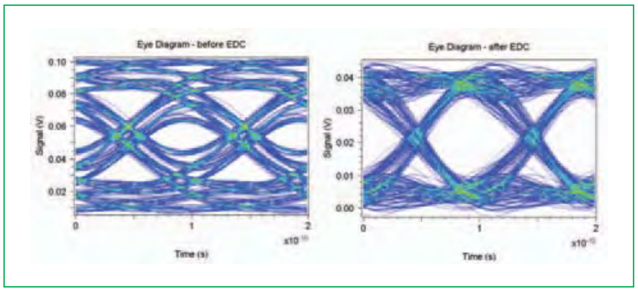
Examples of the uniform and non-uniform meshing of an edge of the metal aperture in the CMOS pixel.

While every problem might not benefit from this feature, some problems can see a dramatic benefit. The CMOS pixel, especially because of sharp field variation at the edges of the metal aperture, can benefit greatly. The use of a non-uniform mesh which is finer at the material interfaces reduced the time and memory requirements for the simulation by approximately a factor of 4 while obtaining the same accuracy found with a uniform mesh.

Electronic Dispersion continued from page i

tation can be based. The most common architecture is based on a combination of a feed-forward equalizer (FFE) and/or decision feedback equalizer (DFE). FFE and DFE are typically multi-tap architectures like classical FIR or transversal (TF) filters, and are effective for ISI compensation. More sophisticated equalization techniques also exist in the form of a maximum likelihood sequence estimator (MLSE) implementation, which uses Viterbi decoder algorithms.

A new model for electronic equalization filter has been added to OptSim to provide the EDC capabilities. RSoft has development plans for adding more advanced equalization techniques as well. Figure 1 shows an example of simulations results for an optical link with EDC. The link under consideration is 10 Gigabit Ethernet link of 300-m reach with 50-micron diameter multimode fiber. Due to the imperfections in the fiber index profile and to the offset at the laser-fiber alignment the resulting differential mode dispersion leads to significant degradation of the received-eye diagram. The EDC block is added at post-detection with the equalization filter's parameters optimized to achieve the best performance. The first plot shows received eye diagram before applying EDC and the second one – after EDC. One can clearly see the eye opening improvement. Corresponding link BER improved after EDC from 3.1x10^{-3} to 3.7x10^{-13} – thereby satisfying the standard BER requirement of 10^{-12} or better. ▬



Eye diagram before and after EDC.

New Fiber Laser and Amplifier Module for OptSim

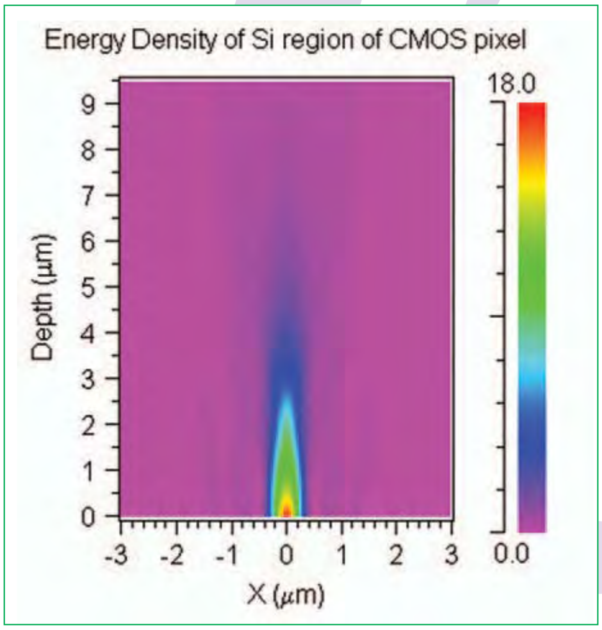
RSoft Design Group partnered with Liekki Corporation, a leading supplier of highly doped optical fibers, to release a new Fiber Laser and Amplifier module for *OptSim*. The module enables the user to incorporate fiber laser and amplifier subsystems designed with Liekki Application Designer (LAD) into *OptSim* system environment. This is the first time a state-of-the-art fiber-laser simulation provided by a manufacturer is made available within an optical communication simulation platform. *OptSim* and LAD users will benefit from the module by being able to comprehensively study the impact of erbium- and ytterbium-doped fiber lasers and amplifiers in the context of full-system designs.

The module supplements a variety of applications already available in *OptSim*, including FTTH/FTTP, PON, DWDM/CWDM, TDMA, OCDMA, CATV, soliton, optical interconnects, and extensive simulations of multimode systems.

Modeling a CMOS continued from page i

evolution of the electromagnetic field within an arbitrary structure. *FullWAVE* correctly models electromagnetic field diffraction, which is increasingly important as pixel pitch decreases, as well as effects such as material dispersion and lossy dielectrics. It also allows for the optimization of structural parameters in order to achieve a desired performance. Also, while this example only simulates a single pixel at a single wavelength, *FullWAVE* can be used to model cross-talk between adjacent pixels and several operating wavelengths.

The CMOS pixel geometry used here is typical for these types of structures: A plane wave is coupled into the CMOS pixel through a lens, passed through a metal aperture to improve collimation and reduce cross-talk between adjacent pixels, and then allowed to be absorbed into a silicon substrate. The amount of power is measured as a function of the distance into the silicon. The latest version of *FullWAVE* utilizes a non-uniform mesh to better model the quickly decaying field at material interfaces and obtain accurate results with a coarser average grid size in less simulation time (see sidebar on page i).

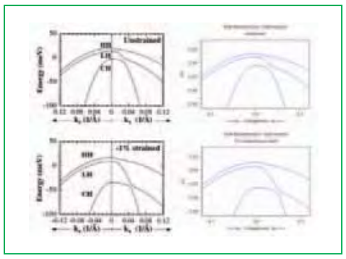


The results of the *FullWAVE* simulation can be seen the figure, which shows the power density in the silicon substrate, as a function of penetration depth, can be seen. This information can be used to efficiently position the active regions used to produce current, as well as an input to an electrical simulator to simulate the performance of the active regions.

As demonstrated, *FullWAVE* provides a convenient way to explore possible CMOS pixel geometries, and can output information needed by an electrical simulator to provide a complete CMOS model. ▬

LaserMOD 2.2.3 is Released with New Simulation Capabilities for GaN systems

Advances in group-III nitrides (GaN, AlN and InN) and their ternary systems have recently allowed numerous photonic device applications to become practical. Their wide band-gaps permit optical transitions in the blue-green spectrum, which is highly desirable for lasers and LEDs used in numerous display and dense storage applications. These systems have garnered much interest in recent years in both industry and the research community. Development continues in the many areas, including room temperature blue-violet InN/GaN- or AlN/GaN-based quantum well lasers [1].

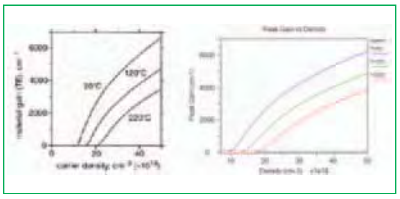


Special care must be taken in the simulation of devices based on GaN compounds, since additional effects such as piezo-electric polarization can become significant in these systems, while they could largely be ignored in devices based on the more standard GaAs or InP material systems. Additionally, GaN lattices can exhibit the wurtzite crystal structure, rather than the zinc-blend structure of GaAs or InP, requiring different material parameter sets for band-structure and gain calculations.

RSoft Design Group's recently released *LaserMOD* 2.2.3 which addresses the needs of active semiconductor device designers exploring applications based on GaN material systems. Simulation capabilities now include a self-consistent 8x8 band KP calculation for wurtzite crystal structures, including piezo-electric polarization effects. Also, included are sets of material data for GaN, AlN, and InN, and the AlGaN and InGaN ternary systems.

The enclosed figures illustrate the use of the tool for calculating band-structure and gain in GaN systems. Fig. 1 shows the GaN (bulk wurtzite) band-structure for no strain (top) and 1% compressive strain (bottom). The results from the literature [2] are shown in Fig. 1 (a), while the results generated with *LaserMOD* are shown in Fig. 1 (b). In Fig. 2, the peak gain of an InGaN(x=.15)/InGaN(x=0.02) 40 Angstrom quantum well structure is tabulated vs carrier density, for 3 different temperatures. Once again, results from the literature [3] are shown in Fig. 2 (a) and results generated with *LaserMOD* are shown in Fig. 2 (b).

LaserMOD 2.2.3 offers GaN device designers the combination of a versatile, user-friendly, and easy to learn GUI with a powerful, robust simulation engine which provides a self-consistent solution of electro-thermal transport and optical field propagation. Additional features recently released include simulation capabilities for distributed feedback lasers. A 2D cross-section taken along the plane that is defined by the growth direction and the propagation axis of the waveguide allows for the simulation of longitudinal spatial hole burning in a variety of structures. Together with the other component design products from RSoft Design Group, *LaserMOD* is well positioned to meet the future design needs of the optoelectronic integrated circuit industry.



References:

[1] Physical Review B, Vol. 61, No. 19, p. 12933.
[2] Physical Review B, Vol. 54, No. 4, p. 2941.
[3] IEE Proc.-Optoelectron., Vol. 149, No. 4, p. 145.

RSoft Assists Queens University in Research Effort

A critical application of the Finite-Difference Time-Domain method in contemporary optics is the study of resonant nanocavities in photonic crystals. Such cavities may have future application in nonlinear switching devices and ultra-low threshold lasers. Photonic crystal nanocavities are classic examples of "open systems"—their coupling to the environment determines critical parameters such as cavity mode lifetimes or *Q*-factors, and spontaneous emission rates. RSoft's FDTD tool *FullWAVE* already provides a sophisticated automated tool "*Q-Finder*" for calculating *Q*-factors. However, the spontaneous emission rate is often expressed in terms of the electromagnetic Green function or its imaginary part, the Local Density of States (LDOS). A complete calculation of the LDOS for a complicated photoniccrystal is a very challenging problem.

Now in a recent article in Physical Review Letters, researchers from Queen's University in Kingston, Ontario and the University of Sydney, led by Prof. Marc Dignam of Queen's and working with RSoft senior scientist Mike Steel, have presented a method that allows the calculation of the LDOS for coupled cavity systems in as little as 1% of the time required

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Briefs

IIT Delhi uses RSoft software in Research

The Fiber Optics Group at the Indian Institute of Technology Delhi has pioneered photonic and optical research and teaching in India. In recent years, the group has worked on Lithium Niobate-based planer waveguides and PBG bandgap fibers. Professor B.P. Pal, who heads the group and supports commercial tools says, "While in the past our group used to develop software for each project, we decided to purchase RSoft software to avoid this repetition. We felt that having the industry standard software packages such as *BeamPROP, FullWAVE, BandSOLVE, GratingMOD, FemSIM,* and *OptSIM,* would provide us with the freedom to design both new components and modify well-known components with new features." He adds, "Our intention has been to use the software to better equip our students for work within optoelectronics related industries."

OptSim Demo CD in new book by Gerd Keiser

RSoft Design Group, Inc is collaborating with Dr. Gerd Keiser to provide a downloadable demonstration version of its award-winning optical communication system simulation software, *OptSim*, in his new book, *FTTX: Concepts and Applications*. This new book published by IEEE Press as part of the Wiley Series in Telecommunications and Signal Processing is a landmark reference for FTTP network design, installation, testing, and maintenance. This book presents fundamental passive optical network (PON) concepts, providing readers with the tools needed to understand, design, and build these new access networks. Topics include the underlying principles and components of optical fiber communications technologies used in access networks, descriptions of PON and fiber-to-the-X (FTTX) alternatives, their application to fiber-to-the-premises (FTTP) networks, and essential measurement and testing procedures for network installation and maintenance.

RSoft at Semicon West

Dr. Brent Whitlock and Dr. Zhengyu Huang of RSoft Design Group presented a talk on "Photonic Design Automation (PDA) Software for Lithography and Optical Metrology" at Semicon West July 11-15, 2006. The talk was during the session "Design for Manufacturing: What is Being Done", and highlighted the continued decrease of feature size, and the necessity for 3D, full-vectorial rigorous electromagnetic simulation for micro-lithography and optical metrology. Advances in electromagnetic numerical simulation techniques, the increasing power of the modern personal computers, and the emergence of inexpensive parallel systems with clustering technology make such simulation feasible in terms of both speed and accuracy. Advanced numerical simulation techniques for lithography and optical metrology include full-vectorial analysis solutions based on Rigorous Coupled Wave Analysis (RWCA) for both 2D and 3D structures. RSoft's *FullWAVE* and *DiffractMOD* were presented as example solutions.

RSoft Assists Queens University continued from page iii

previously. This work was assisted by RSoft's addition of a new generalized overlap monitor to *FullWAVE* and this technique is now available to all RSoft users. It is part of an ongoing research effort at RSoft in simplifying the application of *FullWAVE* to open systems problems.

This work is just one example of the research outcomes from RSoft's ongoing collaboration with the University of Sydney CUDOS group in which RSoft has invested over $100k and which has produced 13 papers in the last three years. This relationship and our research links with Columbia University help to ensure that RSoft products are continually driven by and tested against current research problems.

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M. M. Dignam, D. P. Fussell, M. J. Steel,
C. Martijn de Sterke, and R.C. McPhedran
"Spontaneous Emission Suppression via Quantum Path Interference in Coupled Microcavities"
Phys. Rev. Lett. vol. 96, 103902 (2006)
http://link.aps.org/abstract/PRL/v96/e103902
doi:10.1103/PhysRevLett.96.103902

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