Mixed-mode Optical Design for Optoelectronic Applications

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This paper aims to highlight the variability of tools and methods which are required for the optical design of optoelectronic systems, which may include sources, receivers, refractive and diffractive micro-optical elements as well as waveguides and photonic crystals.

What details of the character of the electromagnetic field in a design are to be considered strongly depends on the systems geometry. High refractive indices and geometry features at wavelength scale or below require vectorial analysis, whereas low index contrast, small numerical aperture (NA) and field diameters well above the wavelength may allow for simple ray optics. If the optical system includes quite different media and different length-scales, due consideration is needed in order to determine a possible design flow which is both sufficiently accurate and numerically feasible. If approximations are unavoidable, the cross-check of the results with complementary methods is a must in order to achieve reliability of the design prior to fabrication. Thus, a variety of different design tools has to be at hand within the design process, for e.g., fibre to photonic crystal coupling, diffractive correction, and light extraction from OLED devices, for example.

If the coupling from a telecom fibre to a defect waveguide in a photonic crystal by means of free-space micro-optics is considered, it is intuitively clear that FDTD isn't applicable for the whole geometry, whereas considerable parts of the system are best handled with ray-tracing, simply. In order to improve design efficiency, a semi-analytical model to calculate the transmission from the focal field (foc) to the intended waveguide mode (w) as an integral over a coupling plane (cp)

$$T=\frac{\left|\iint\limits_{(cp)} dxdy\left[\vec{E}_{Foc}^{(t)^*}\times\vec{H}_{W}^{(t)}+\vec{E}_{W}^{(t)}\times\vec{H}_{Foc}^{t^*}\right]_z\right|^2-\left|\iint\limits_{(cp)} dxdy\left[\vec{E}_{Foc}^{(t)}\times\vec{H}_{W}^{(t)}-\vec{E}_{W}^{(t)}\times\vec{H}_{Foc}^{t}\right]_z\right|^2}{\iint_{(cp)} dxdy\left[\vec{E}_{Foc}^{(t)^*}\times\vec{H}_{W}^{(t)}+\vec{E}_{W}^{(t)}\times\vec{H}_{Foc}^{(t)^*}\right]_z}$$

can be used advantageously [1], which is based on the reciprocity theorem for photonic crystal waveguides [2]. To confirm the result, FDTD is a proper means now since the volume required for the analysis just allows for a discretisation which fits into a PCs memory.

Diffractive elements in micro-optical systems call for separate investigation. Scalar diffraction theory turns out to be a simplified approximation if e.g. diffractive corrections are applied to high NA micro-lenses. In order to incorporate efficiencies and phases for different diffraction orders accurately in an overall design, rigorously coupled wave analysis applied to grating problems is an adequate means. The coupling of grating analysis and a ray-trace engine is a must, too, if light extraction from OLEDs by means of periodic structures is investigated. Furthermore, for the OLED device the coupling of light from the radiating dipoles into slab guided and leaky modes requires special consideration, since this may reduce the overall device efficiency remarkably. There, a Green-functions based analysis tool is an adequate means for design improvements.

Although commercially available design tools nowadays offer a wide range of functionality, these examples which all stem from applied research show that the diversity of optical applications requires that the designer can fall back to different design tools, to appropriate interface tools, and to a sufficiently broad knowledge in electromagnetics.

REFERENCES

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