Session 3A2
Optics and Photonics

Numerical Analysis of Light-wave Scattering from Blue Laser Optical Disk Models with Random Rough Surfaces

T. Kojima and T. Kawai
Kansai University, Japan

We have analyzed the scattering of an optical wave from various models of optical disk by numerical simulation methods, e.g., the boundary element method (BEM) or the finite-difference time domain (FDTD) method in the previous paper [1, 2]. In general, the boundary surface between two different layers of multilayered disk structure has more or less microscopic roughness.

In order to consider the influences of the surface roughness on the scattering characteristics, we have presented the numerical simulation of the scattering of a Gaussian beam from optical disk structures with random rough surfaces.

In the present paper, the deterioration of the detected signal characteristics due to the surface roughness is estimated by using numerical simulation models. The computer-generated rough surface model [3] is applied to the multilayered disk structures for blue laser. The scattered light-intensity collected in the aperture of an object lens can be calculated by FDTD method. It is shown that the sum- and differential signal outputs are estimated by using numerically calculated scattered intensity of light. An example of the numerically calculated cross talk characteristics between two adjacent recording marks is also shown and discussed.

REFERENCES

1. Kobayashi, I., T. Kojima, S.-I. Fukai and Y. W. He, "Numerical analysis of light-beam diffraction from magneto-optical disk medium by FDTD Method," *IEICE Trans. Electron*, Vol. E-84-C, No. 9, 1189–1196, Sept. 2001.
2. Kojima, T., H. Hotta and Y. Asano, "Three-dimensional (FD)2TD analysis of light-beam diffraction from phase-change optical disks with land/groove structures," *IEICE Trans. Electron*, Vol. E-86-C, No. 9, 1861–1867, Sept. 2003.
3. Kojima, T. and T. Yamazoe, "Scattering of a focused beam from random rough surface - Analysis by computer simulation," *Proc. of 24th General Assembly of the International Union of Radio Science*, Aug. 1993.

Optically Tunable Photonic Crystal Reflectance Filter

D. W. Dobbs and B. T. Cunningham
University of Illinois at Urbana-Champaign, USA

We have demonstrated a photonic crystal structure whose properties are tunable with laser illumination through the incorporation of a nonlinear dye. Laser illumination causes a change in the bulk refractive index of a polymer that is doped with the dye, leading to controlled tuning of the photonic crystal reflectance spectrum.

The device, shown in Figure 1, consists of a one-dimensional periodic ($\Gamma = 550\,\mathrm{nm}$) surface structure fabricated on a low refractive index plastic substrate that is overcoated with a layer of high refractive index TiO_2. The process is performed over large surface areas on continuous rolls of plastic film. A solution containing 95% polymethylmethacrylate (PMMA) and 5% N-Ethyl-N-(2-hydroxyethyl)-4-(4-nitrophenylazo)aniline by weight is spin-coated onto the structure, resulting in a solid film with a thickness of several microns. When the fabricated structure is illuminated with broadband light at normal incidence with the light polarization perpendicular to the grating lines, a narrow band of wavelengths ($\lambda = 891\,\mathrm{nm}$, $FWHM = 1\,\mathrm{nm}$) is strongly reflected. We have demonstrated that upon laser illumination, the wavelength of the reflection resonance can shift to lower wavelengths by $> 2\,\mathrm{nm}$, and that the resonance returns to its original wavelength when the illumination is turned off. For the resonance-tuning effect to be achieved, the wavelength of the laser must be within the absorption spectrum of the dye, which is centered at a wavelength of 500 nm. As shown in Figure 3, we have characterized the switching speed and dependence of the wavelength shift with laser intensity. Because the switching behavior is independent of the polarization of the incident laser beam, the bulk refractive index change is likely caused by the trans-cis excitation of dye molecules. Numerical simulations show that the magnitude of the bulk refractive index change in the dye-doped polymer film is as large as 0.01.

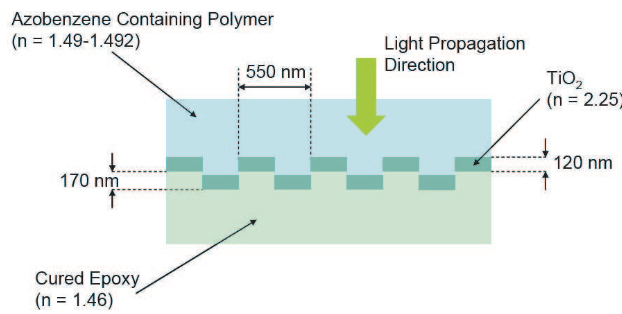

Figure 1.

Because the device structure can be fabricated inexpensively in plastic over large areas, and because a high density of independently addressable locations will be achieved due to lateral optical confinement by the photonic crystal, we expect the new device to find applications in optical computing, storage, switching, and multiplexing.

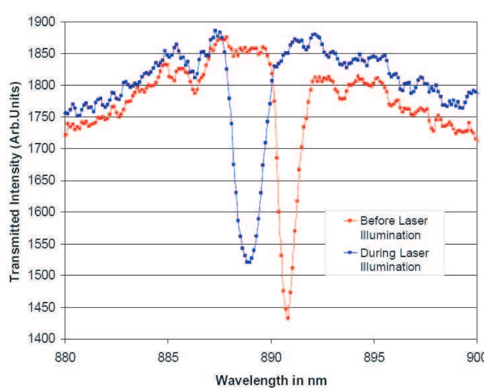

Figure 2.

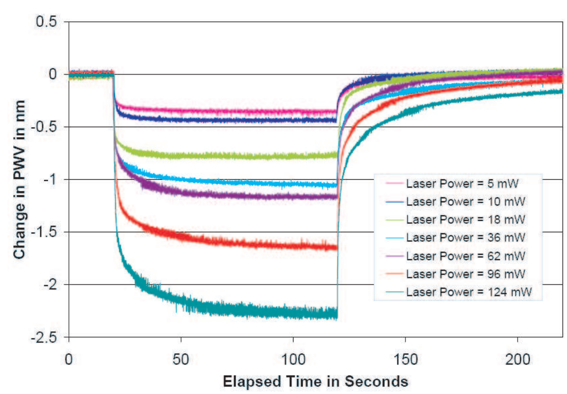

Figure 3.

Focal Switch Effect of Focused Cosine Gaussian Beam

C. J. Peng
Jingdezhen Comprehensive College, China

J. L. Chen
MinJiang University, China

F. X. Lu
Fuzhou Kaixin Real Estate Co., Ltd, China

The light intensity on axis and the focal switch effect of cosine Gaussian beam focused by a thin lens without aperture is studied in detail by using Collins formula. The third-order algebraic equation determining the position of the axial maximum intensity and the formula of the relative transition height are derived. It is shown that the relative focal shift and the focal switch depend on the optical system parameter s/f, beam parameter $\alpha = w_0\Omega_0$, and Fresnel number of beam N_w. Numerical calculation results are presented to illustrate the theoretical predictions. It is shown that if the beam parameter α is smaller than 1, there only exist one axial irradiance maximum, and the focal shift changes slowly with the change of the optical system parameter. So the focal switch of cosine Gaussian will not occur. When the beam parameter α is bigger than 1, the on-axis light intensity is split into two-peaks, which are separately at the both sides of the geometrical focus. The two peaks reach the same height when the optical system parameter s/f equals 1. The relative focal shift changes from negative to positive number, and the focal switch occurs at this point. For example, when the parameters for calculation are Fresnel number of beam $N_w = 2$ and the beam parameter $\alpha = 1.5$, the relative focal shift changes from the left of geometrical focus ($z_{f1} = -0.1779$) to the right of geometrical focus ($z_{f2} = 0.1779$). It is also found that the relative transition height $\Delta z_f = |z_{f1} - z_{f2}|$ increases with the increase of the beam parameter s/f, and decreases with the increase of Fresnel number of beam N_w. Numerical calculation results show that when the beam parameter α is bigger than 1, there exists a hollow between two peaks on the axiswhich becomes deep with the increase of the beam parameter. When the beam parameter is bigger than 3.5, the intensity near the hollow approximately equals zero.

Band-stop Filters in Microstrip Technology with Non-periodic Frequency Responses

I. Arnedo, T. Lopetegi, D. Benito, F. J. Falcone, and M. A. G. Laso
Universidad Pública de Navarra, Spain

Periodic structures have been always an important research issue within the microwave community. One of their well-known drawbacks is that the frequency responses of classical band-stop periodic structures exhibit undesirable stop-bands at the harmonics of the design frequency. On the other hand, Photonic Band-Gap (i. e., band-stop) structures in microwave technology recovered the interest in the periodic structure theory in the last years, proposing a new nondiscrete approach [1] that made possible a huge number of brand new devices. In this paper, single and doublefrequency-tuned Photonic Band-Gap microstrip filters with controlled suppression of the spurious bands at the harmonics of the designed frequencies are presented, based on the Coupled-Mode Theory [2].

Periodic band-stop structures following sinusoidal PBGtype etching profiles in the ground plane of a microstrip line [1, 2] or modulating the upper strip [3] have been profusely reported in the literature. Assuming that only the fundamental quasi-TEM microstrip mode is propagating, its forward and backward waves are related by means of the socalled coupling coefficient, $K(z)$, which is proportional to the first derivative of the impedance to the propagation axis, z [2]. Provided the etching profile or modulated strip-width are periodic, $K(z)$ may be expressed through its Fourier series where K_n are the coefficients of this series. Almost exact analytical expressions may be obtained for the central frequency, $f_n = c \cdot n/(2 \cdot \Lambda \cdot \sqrt{\varepsilon_{eff}})$, rejection level, $|S_{21}|_n = \mathrm{sech}(|K_n| \cdot L)$, and bandwidth between zeroes of reflection, $BW_n = c \cdot |K_n|/(\pi \cdot \sqrt{\varepsilon_{eff}}) \cdot \sqrt{1 + (\pi/K_n \cdot L)^2}$, of the n-th stop-band, which relate these parameters to the n-th coefficient of the Fourier series K_n (being c the speed of light in vacuum, and ε_{eff} the effective relative dielectric permittivity). The previous equations show that in order to suppress all the harmonic pass-bands, we would have to design adequately the perturbation so that $K_n = 0$ for $n \neq \pm 1$, obtaining for instance a nearly sinusoidal strip-width modulation.

Harmonic stop-bands may be observed in measurements for strip-width sinusoidal modulation of a microstrip line with period $\Lambda = \pi/200$ and length $L = 8 \cdot \Lambda$. Perfectly sinusoidal perturbation leads to a quasi-sinusoidal coupling coefficient, which provides not very deep harmonic stopbands. The strip-width modulation is now altered so that $K(z)$ is perfectly sinusoidal ($K_{\pm 1} = 35\, m^{-1}$ and $K_n = 0$ for $n \neq \pm 1$). Now, in measurements, harmonic stop-bands are perfectly suppressed.

Interesting design capabilities can be shown. For instance, for a filter with two stop-bands at 3 GHz and 5 GHz, 20-dB attenuation and 1GHz bandwidth each, a doubly periodic ($\Lambda_1 = 19.12$ mm and $\Lambda_2 = 11.47$ mm) modulation along a $L = 172.08$ mm-long device with $|K_{\pm 1}|_{1,2} = 19.17\,\mathrm{m}^{-1}$ may fulfil these requirements. The agreement between simulation and measurement results is very good.

REFERENCES

1. Laso, M. A. G., T. Lopetegi, M. J. Erro, D. Benito, M. J. Garde, and M. Sorolla, "Multiple-frequency-tuned photonic bandgap microstrip structures," *IEEE Microwave and Guided Wave Letters*, Vol. 10, No. 6, 220–222, June, 2000.
2. Lopetegi, T., M. A. G. Laso, M. J. Erro, M. Sorolla, and M. Thumm, "Analysis and design of periodic structures for microstrip lines by using the coupled mode theory," *IEEE Microwave and Wireless Components Letters*, Vol. 12, No. 11, 441–443, Nov. 2002.
3. Nair, N. V. and A. K. Mallick, "An analysis of a widthmodulated microstrip periodic structure," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 32, No. 2, 200–204, Feb. 1984.

Time-domain Statistics of Multi-layer Optical Filters

H. E. Rowe
Stevens Institute of Technology, USA

We calculate the time-response statistics for multi-layer optical filters with random errors in layer thickness or index of refraction.

Exact statistics have been determined for the reciprocal transfer function in the wavelength domain, using Kronecker product methods. Transfer function statistics are then obtained by applying perturbation theory to these exact results. This is valid because useful devices depart only slightly from their ideal design. These approximate results have been verified by comparison with exact results for special cases. First- and second-order transfer function statistics in the wavelength domain have previously been presented.

The average transfer function, varying with frequency or wavelength, is deterministic. The transfer fluctuations about the average are random. The covariance of the transfer function fluctuations in the wavelength domain has been calculated using the above methods.

The wavelength λ is a natural parameter for calculating transmission statistics. However, we require similar results as functions of frequency f in order to determine time-domain statistics. Thus for a random transfer function, the expected value of the square of the envelope of the impulse response is proportional to the Fourier transform of the covariance of the transfer function.

We separate the transfer function into deterministic and random components:

$$T(f) =< T(f) > +\Delta T(f).$$

The covariance of the random component is

$$C(f_1, f_2) =< \Delta T(f_1)\ \Delta T * (f_2) > .$$

The impulse responses for these two components are their Fourier transforms:

$$G(t) < - >< T(f) >;\ g(t) < - > \Delta T(f).$$

We use the symbol $< - >$ to denote the Fourier transform relationship. The corresponding envelopes for these time functions are $r_G(t)$ and $r_g(t)$. Then $< |r_g(t)|^2 >$, the average square envelope of the random impulse response, is calculated from the covariance C of the random component of the transfer function.

We present results for a 13-layer band-pass optical filter.

REFERENCES

1. Rowe, H. E., *Electromagnetic Propagation in Multi-Mode Random Media*, John Wiley, New York, 1999.
2. Rowe, H. E., "Second-order statistics of multi-layer optical coatings," *PIERS 2002 Proceedings*, 310, July 1–5, 2002.

Direct Light to RF Fiber Antenna

J. Flattery[1], **T. L. Jamison**[2], **and P. Kornreich**[1]

[1]Syracuse University, USA
[2]NASA Goddard Space Flight Center, USA

We are developing an antenna that directly converts a modulated optical signal to microwave radiation. This is useful as an element in a Phased Array Antenna (PAA). Currently signals to each element of a PAA are supplied through an optical fiber. The signal is detected, converted to an electronic form, amplified and applied to the antenna element. The direct optical conversion system eliminates the microwave amplifier at each antenna element. The antenna element consists of a single mode optical fiber that has two dissimilar semiconductor layers at the core cladding boundary as shown in Fig. 1. Since the two semiconductor layer structure does not have inversion symmetry there will be a first order non linear effect which is much larger than higher order non linear effects used in conventional non linear fibers. Two optical signals that differ in frequency by the microwave frequency propagate through the fiber1. The large nonlinearety of the fiber causes mixing of the signals. Signals at the sum and difference frequency are obtained. The difference frequency is the microwave frequency. The fiber will not guide signals at the microwave frequency. These will be radiated by the fiber section. Thus the fiber becomes a microwave antenna. The sum signal is radiated out at the top of the fiber.

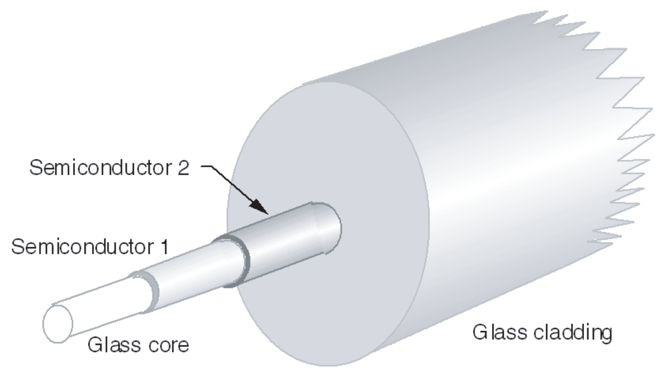

Figure 1: Optical fiber with two thin semiconductor layers at the core cladding boundary.

REFERENCES

1. Zamuda, H., et al., "Photonic generated true time delay phased array applications," USAF Rome Lab Report, No. A532853, Decdmber 1998.

Efficient Tool for Bend Optimization in Photonic Crystals

L. Dekkiche and R. Naoum
University Djillali Liabes of Sidi-Bel-Abbes, Algeria

The realization of efficient sharp and compact waveguide bends is still a challenging task in microoptics. With the introduction of photonic crystals (PC) major interest has also focused on the issue of efficient waveguide bends embedded in PC. There are various proposals for bend design in order to minimize losses. Examples smoothening the sharp bends, introducing cavities or intermediate straight sections or placing smaller holes around the bend.

In this work we use the method of topology optimization to maximize the energy flow through the waveguide and thus reduce unwanted reflections from the waveguide bend to a minimum. We specify a design area in the vicinity of the waveguide and distribute the material in this domain to maximize the energy flow. The flow through the waveguide is found by computing the poynting vector at the output waveguide port.

We have demonstrated 1.55 μm wavelength light wave through a simple 90° sharply bent waveguide formed in a square lattice two dimensional photonic crystal (2DPC). The in-plane guiding within the planar PC structure is based on a W1 defect waveguide (A single line defect acting as a light channel in the $G-K$-direction) whereas for the vertical light confinement we rely in a slab waveguide formed by the low index contrast material system InGaAsP/InP. To achieve a reasonable bandgap around 1.55 μm the PC consists of a lattice of holes with a filling factor of 40%. Such propagation has not previously been experimentally confirmed.

The most promising structure was simulated with a 2D-FDTD program. Since we want to use this device around 1550 nm we calculate the lattice constant to be 430 nm and obtain therefore a hole radius of 141.9 nm respectively.

This optimization step has resulted in 2DPC bend that shows a power transmission of at least 100% over a wavelength of 1550 nm.

Statistical Dynamics of Dispersion-managed Optical Solitons

A. Biswas
Delaware State University, USA

The statistical dynamics of dispersion-managed optical solitons is studied in presence of stochastic perturbation term, by the aid of soliton perturbation theory. The super-Gaussian pulses are considered and the corresponding langevin equations are derived and analysed. It is shown that in presence of the perturbation term, the soliton propagates through the fiber with a fixed mean value of the soliton energy.

A Boundary Element Method for the Analysis of Inhomogeneous Photonic Crystals

F. Seydou and T. Seppanen
University of Oulu, Finland

A fast numerical method for determining photonic bandgaps in composite and inhomogeneous dielectric materials is developed.

It is known that for the propagation or scattering of electromagnetic waves in a medium containing M dielectric bodies arranged periodically (photonic crystal), there exist refractive indices for which such structures have bandgaps, i.e., frequencies for which no waves can propagate inside. Such crystals have many technological applications (fiber optics, cellular telephones, semiconductor industry, etc.). The main purpose of this work is precise numerical simulations on novel dispersive and refractive phenomena in photonic crystal waveguides. In detail we study the influence of specially configured crystal inhomogeneities and physical boundary conditions to tailor the performance of planar and finite 2D-photonic bandgap structures. In order to sufficiently high accuracy in the simulations our calculations are based on a rigorous scattering theory for finite size two-dimensional photonic crystals. The results will be compared with other state-of the art algorithms. In particular, we compute the transmitted wave from an incident plane wave and analyze it for different angles of incidence, and we try and find the frequencies that generate the prohibited waves. In this work we choose a method that is based on boundary integral equations. We derive single integral equations on each of the interfaces between two regions by using a hybrid method of layer potentials and Green's formula. The integral equation we need to solve is of Fredholm type and the problem can be shown to be well-posed. Our technique has many distinct advantages. First, since the approximations are made on the boundary we reduce the dimension of the problem from N to $N-1$. Second, our formulation is different than the usual formulation since for dielectrics (in electromagnetic problems), the number of unknowns is reduced by half. The only drawback is that we have, as usual for BIE, dense matrices in the resulted linear algebraic systems. But this can be remedied by using fast multipole algorithms. Details of the numerical implementation and results will be presented. We also analyze the effect of defects, that is the case when periodicity is violated.