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Modeling of Multimode Interference Electro-optical Switching Structures on a Semiconductor Substrate

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Abstract

A new rigorous modal analysis is proposed for analyzing multimode interference (MMI) structures. This technique is based on describing the optical field in the input and output waveguides by their guided and radiation modes while in the multimode section by its guided modes only since usually it supports large number of them. We account for the reflection occurring at both input and output interfaces by considering the continuity of the electric and magnetic fields. Hence we could define a transmission and reflection matrices for each interface. The formulation of the propagator in matrix form enables us to account for the multiple reflection inside the structure. We finally achieve an analytical formula for transmission and reflection matrices that relate the input modes' amplitudes to the transmitted and reflected modes' amplitudes taking multiple reflections into account. This technique is adequate for both strong and weak guiding structures. It shows results that resemble experimental published data. It shows also good results in comparison with Beam Propagation Method (BPM) for weak guiding structures and Self Imaging Technique (SIT) for strong guiding structures. This technique could also predict short distances for the multimode section for new self images using weak guiding structure that are verified by the BPM and ray optics.

List of Symbols

$\bar{a}$	Polarization unit vector.
$A(r,t)$	Potential vector of electromagnetic wave.
$A(\sigma)$	Radiation mode amplitude.
α	Absorption coefficient.
α_p	Index loss variation ratio.
β	Mode propagation constant in the z direction.
c	Free space speed of light.
c_v	Amplitude of guided mode.
$\aleph_v^{nq}(z)$	Hole envelope function.
$\aleph_c^{p}(z)$	Electron envelope function.
dn	Refractive index difference.
$\delta(z)$	Delta-Dirac function.
$\Delta n^{'}$	Induced change in the real part of the refractive index.
$\Delta n^{''}$	Induced change in the imaginary part of the refractive index.
E_c	Conduction band edge.
E_f	Fermi level energy.
E_g	Band gap energy.
$E_{initial}$	Initial electron energy.
E_{final}	Final electron energy.
E_v	Valence band edge.
$E(x,z)$	Electric field distribution.
ε_o	Free space permittivity.

ε_r	Relative permittivity.
$f(E)$	Fermi-Dirac distribution function.
$\varphi_g(x,\beta_g)$	Field distribution of guided modes.
$\phi(x,\sigma)$	Field distribution of radiation mode.
γ_c	Cross talk at cross state.
γ_d	Cross talk at direct state.
Γ	Extinction ratio.
$\hbar$	Plank's constant divided by 2π.
$H(x,z)$	Magnetic field distribution.
H'_{cv}	Matrix element.
H'_{op}	Perturbation operator.
I_{av}	Average field intensity.
I_o	Input field intensity.
$\bar{I}$	Identity matrix.
K	Boltzmann constant.
$\bar{k}_c, \bar{k}_v$	Electron momentum vector in conduction and valence bands.
k_x, k_y	Mode propagation constant in the x, y directions.
$\bar{k}_{ph}$	Photon momentum vector.
κ	Coupling constant.
L_π	Beating length.
λ_o	Free space wavelength.

m	Free electron mass.
m_e^*	Electron effective mass.
m_h^*	Hole effective mass.
m_r^*	Reduced effective mass.
μ_o	Free space permeability.
$n(x,y,z)$	Refractive index distribution.
n', n''	Real and imaginary parts of the refractive index.
n_c	Cladding refractive index.
n_{eff}	Mode effective index.
n_g	Guide refractive index.
N_J^{3D}	Three dimensional joint density of states.
$\overline{P}_{cv}^{2D}$	Two dimensional momentum matrix elements.
$\overline{P}_{cv}^{3D}$	Three dimensional momentum matrix element.
q	Electron charge.
$\bar{r}$	Position vector.
R	Absorption rate.
$\overline{R}$	Reflection matrix.
R_{ex}	Exciton Rydberg energy.
$\overline{R}_{mult.-ref.}$	Reflection matrix with multiple reflection.
ρ_{2D}	Two dimensional density of states.
ρ_{3D}	Three dimensional density of states.

S	Spin quantum number.
$S(k_1,k_2)$	Transition probability.
σ	Radiation mode transverse propagation constant.
T	Temperature in Kelvin degree.
$\overline{T}$	Transmission matrix.
$\overline{T}_{mult.-ref.}$	Transmission matrix with multiple reflection.
$U_v(\bar{r})$	Electron periodic part of the initial wave function.
$U_c(\bar{r})$	Electron periodic part of the final wave function.
V	Applied voltage.
W	Quantum well width.
W_{eff}	Guide effective width.
W_{ph}	Guide physical width.
ω	Angular frequency.
$\psi_{k1}(t,\bar{r},k_1)$	Initial electron wave function.
$\psi_{k2}(t,\bar{r},k_2)$	Final electron wave function.
$\psi_v(x)$	Field distribution of guided mode.
$\psi\ (x,y,z)$	Electric field component of electromagnetic wave.
$\Psi(x,z)$	Any field distribution.

Key Words

BPM	Beam Propagation Method.
EIM	Effective Index Method.
FFTBPM	Fast Fourier Transform Beam Propagation Method.
FI	Fourier Image.
MMI	Multimode Interference.
MQW	Multiple Quantum Well.
QW	Quantum Well.
RSM	Radiation Spectrum Method.
SC	Semiconductor.
SI	Self Imaging.
SIT	Self Image Technique.
TE	Transverse Electric.
TM	Transverse Magnetic.
VLP	Voltage Length Product.

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