各向同性光波导受到各向同性微扰时的严格矢量耦合模理论*

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摘　要　从 Maxwell 方程出发,推导出各向同性光波导受到各向同性微扰时严格的非正交矢量耦合模理论,在耦合系数的表达式中发现不包含 Wei-Ping Huang 的准矢量耦合模理论中的偏振耦合项,但在推导过程中曾出现过偏振耦合项.最后认为这是由于偏振耦合项是二阶小量,而弱导近似忽略了与之相等的二阶小量耦合项.因此,严格的矢量耦合模理论不存在该项而准矢量耦合模理论可把偏振耦合项作为修正项.

关键词　光波导;矢量耦合模理论;偏振耦合项;麦克斯韦方程

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0　引言

耦合模理论作为有效的数学工具分析电磁场中的模式耦合[1~3],在耦合波方程的推导过程中,往往针对某类耦合用了一些近似处理.常规耦合模理论[4~6]为了分析单个波导或几乎完全相同波导之间的耦合,提出了模式正交性,但它用于分析不同波导之间的耦合时,发现不满足无损波导的模式自洽性,直到最后提出模式非正交性[7,8],引入功率交叉性才得以解决,不过最后发现它不满足于 Maxwell 方程和边界条件.最近 A. N. Kireev[9,10] 等人在介电常量的横向为分段常函数的近似前提下,即 $\nabla\varepsilon(x,y)=0$,横向电磁场的扩展中包含了纵向电磁场的变化,而且扩展系数不相同,得到了对称矢量耦合模理论,可用以分析阵列波导间的耦合.

对高速率高容量的光通信,偏振现象越来越受到人们的重视,特别是在光孤子传输中,同时对光器件也提出了更高的要求.Wei-Ping Huang 提出了非正交偏振耦合模理论[11]力图解释偏振耦合现象,他是在标量耦合模理论的基础上,用矢量性作为修正项,从而在耦合系数的表达式中得到了偏振耦合项,并用此理论分析了一些光波导器件中的偏振特性[12,13].但发现,他是在弱导的前提下得到的结果,对各向同性光波导,严格的非正交矢量耦合模理论的耦合系数表达式中并未出现偏振耦合项,这主要是因为偏振耦合项本身是二阶小量,而弱导近似的同时忽略了其中包含的二阶小量耦合项,而且最终证明偏振耦合项在我们的耦合系数中曾经出现过,但它与因弱导而忽略的二阶耦合项恰恰相同.在这方面已经做了深入的研究[14],严格地推导出各向同性光波导受到各向异性微扰时的耦合波方程,发现也不存在偏振耦合项,但在弱导近似下各向异性光波导受到任意微扰时的耦合模理论中,出现了偏振耦合项和双折射耦合项.本文从 Maxwell 方程出发,严格地推导出各向同性波导受到各向同性微扰时的非正交矢量耦合模理论,并对现有理论进行比较与分析.

1　理论分析

假设导波介质是线性、无损耗,磁导率和真空一样,场随时间的变化为 $\exp(-\mathrm{j}\omega t)$.从麦克斯韦原始方程可推导出各向同性光波导受到各向同性微扰时场的纵向分量和横向分量满足下列关系式[15]

$$\nabla_t\times\boldsymbol{E}_t=\mathrm{j}\omega\mu_0\boldsymbol{H}_z \tag{1a}$$

$$\nabla_t\times\boldsymbol{H}_t=-\mathrm{j}\omega\varepsilon\boldsymbol{E}_z \tag{1b}$$

$$\nabla_t\times\boldsymbol{E}_z+\hat{z}\times\frac{\partial\boldsymbol{E}_t}{\partial z}=\mathrm{j}\omega\mu_0\boldsymbol{H}_t \tag{1c}$$

$$\nabla_t\times\boldsymbol{H}_z+\hat{z}\times\frac{\partial\boldsymbol{H}_t}{\partial z}=-\mathrm{j}\omega\varepsilon\boldsymbol{E}_t \tag{1d}$$

式中下标为 t 表示场的横向分量,下标为 z 表示场的纵向分量,介电常量,$\varepsilon(x,y,z)=\varepsilon_0(x,y)+\varepsilon(x,y,z)$,$\varepsilon_0$ 为正规光波导的介电常量,$\tilde{\varepsilon}$ 为由波导本身缺陷或外界引起的微扰项.由于波导是各向同性的且微扰也是各向同性的,所以介电常量 $\tilde{\varepsilon}$、ε 都可作为标量处理.对式(1a)和式(1b)分别取旋度并利用

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式(1c)和式(1d)可得

$$-\frac{1}{j\omega\mu_0}\nabla_t\times(\nabla_t\times\boldsymbol{E}_t)-(\hat{z}\times\frac{\partial\boldsymbol{H}_t}{\partial z})=j\omega\varepsilon\boldsymbol{E}_t \quad (2)$$

$$\frac{1}{j\omega\varepsilon}[\nabla_t\times(\nabla_t\times\boldsymbol{H}_t)]+\frac{1}{\varepsilon}[(\nabla_t\varepsilon)\times\boldsymbol{E}_z]=-j\omega\mu_0\boldsymbol{H}_t+\hat{z}\times\frac{\partial\boldsymbol{E}_t}{\partial z} \quad (3)$$

对于没受任何微扰时的理想正规光波导，介电常量 $\varepsilon=\varepsilon_0$，横电场和横磁场的场分布可写为

$$\begin{bmatrix}\boldsymbol{E}_t\\ \boldsymbol{H}_t\end{bmatrix}=\begin{bmatrix}\boldsymbol{e}_t(x,y)\\ \boldsymbol{h}_t(x,y)\end{bmatrix}\exp(j\beta z) \quad (4)$$

这里的 $\boldsymbol{e}_t(x,y)$ 和 $\boldsymbol{h}_t(x,y)$ 满足横向的波动方程．在这种情况下，式(2)和式(3)变为

$$-\frac{1}{j\omega\mu_0}\nabla_t\times(\nabla_t\times\boldsymbol{e}_t)-j\beta(\hat{z}\times\boldsymbol{h}_t)=j\omega\varepsilon_0\boldsymbol{e}_t \quad (5)$$

$$\frac{1}{j\omega\varepsilon_0}[\nabla_t\times(\nabla_t\times\boldsymbol{h}_t)]+\frac{1}{\varepsilon_0}[(\nabla_t\varepsilon_0)\times\boldsymbol{e}_z]=-j\omega\mu_0\boldsymbol{h}_t+j\beta(\hat{z}\times\boldsymbol{e}_t) \quad (6)$$

由于光波导受到折射率微扰，本身几何尺寸没发生变化，因此可近似的把非正规光波导的场看作是正规光波导场的线性叠加，则

$$\boldsymbol{E}_t=\sum_\mu a_\mu(z)\boldsymbol{e}_{\mu t}\quad \boldsymbol{H}_t=\sum_\mu b_\mu(z)\boldsymbol{h}_{\mu t} \quad (7)$$

由式(1b)和 $\nabla_t\times\boldsymbol{h}_t=-j\omega\varepsilon_0\boldsymbol{e}_z$ 可知

$$\boldsymbol{E}_z=-\frac{1}{j\omega\varepsilon}\nabla_t\times\boldsymbol{H}_t=\sum_\infty\frac{\varepsilon_0}{\varepsilon}b_\mu(z)\boldsymbol{e}_{\mu z} \quad (8)$$

把式(7)和式(8)代入式(3)，并与式(6)相减后，在等式两边同时点乘 $\boldsymbol{h}_{\nu t}^*$，再在无穷平面上积分并化简可得

$$\sum_\mu\frac{da_\mu}{dz}\iint_\infty(\boldsymbol{e}_{\mu t}\times\boldsymbol{h}_{\nu t}^*)\cdot\hat{z}dA=\sum_\mu\iint_\infty\frac{1}{j\omega}(\frac{1}{\varepsilon}-\frac{1}{\varepsilon_0})\boldsymbol{h}_{\nu t}^*\cdot[\nabla_t\times(\nabla_t\times\boldsymbol{h}_{\mu t})]dAb_\mu(z)+\sum_\mu\iint_\infty\boldsymbol{h}_{\nu t}^*\cdot\frac{1}{\varepsilon}[(\nabla_t\varepsilon)\times(\frac{\varepsilon_0}{\varepsilon}\boldsymbol{e}_{\mu z})]dAb_\mu(z)-\sum_\mu\iint_\infty\boldsymbol{h}_{\nu t}^*\cdot[\frac{1}{\varepsilon_0}(\nabla_t\varepsilon_0)\times\boldsymbol{e}_{\mu z}]dAb_\mu(z)+\sum_\mu j\beta_\mu\iint_\infty(\boldsymbol{e}_{\mu t}\times\boldsymbol{h}_{\nu t}^*)\cdot\hat{z}dAb_\mu(z) \quad (9)$$

对式(9)右边第一项可化简为

$$\iint_\infty\frac{1}{j\omega}(\frac{1}{\varepsilon}-\frac{1}{\varepsilon_0})\boldsymbol{h}_{\nu t}^*\cdot[\nabla_t\times(\nabla_t\times\boldsymbol{h}_{\mu t})]dA=-\iint_\infty\frac{1}{j\omega}(\frac{1}{\varepsilon}-\frac{1}{\varepsilon_0})\boldsymbol{h}_{\nu t}^*\cdot[\nabla_t\times j\omega\varepsilon_0\boldsymbol{e}_{\mu z}]dA=-\iint_\infty(\frac{1}{\varepsilon}-\frac{1}{\varepsilon_0})\boldsymbol{h}_{\nu t}^*\cdot[(\nabla_t\varepsilon_0)\times\boldsymbol{e}_{\mu z}+\varepsilon_0(\nabla_t\times\boldsymbol{e}_{\mu z})]dA=\iint_\infty(\frac{1}{\varepsilon}-\frac{1}{\varepsilon_0})(\nabla_t\varepsilon_0)\cdot(\boldsymbol{h}_{\nu t}^*\times\boldsymbol{e}_{\mu z}]dA-\iint_\infty\frac{\tilde{\varepsilon}}{\varepsilon}[\nabla_t\cdot(\boldsymbol{h}_{\nu t}^*\times\boldsymbol{e}_{\mu z}-(\nabla_t\times\boldsymbol{h}_{\nu t}^*)\cdot\boldsymbol{e}_{\mu z}]dA=-\iint_\infty\frac{\tilde{\varepsilon}}{\varepsilon\varepsilon_0}(\nabla_t\varepsilon_0)\cdot(\boldsymbol{h}_{\nu t}^*\times\boldsymbol{e}_{\mu z}]dA-\iint_\infty\nabla_t\cdot[\frac{\tilde{\varepsilon}}{\varepsilon}(\boldsymbol{h}_{\nu t}^*\times\boldsymbol{e}_{\mu z}]dA+\iint_\infty(\nabla_t\frac{\tilde{\varepsilon}}{\varepsilon})\cdot[(\boldsymbol{h}_{\nu t}^*\times\boldsymbol{e}_{\mu z})]dA+\iint_\infty\frac{\tilde{\varepsilon}}{\varepsilon}[(\nabla_t\times\boldsymbol{h}_{\nu t}^*)\cdot\boldsymbol{e}_{\mu z}]dA=-\iint_\infty\frac{\tilde{\varepsilon}}{\varepsilon\varepsilon_0}(\nabla_t\varepsilon_0)\cdot(\boldsymbol{h}_{\nu t}^*\times\boldsymbol{e}_{\mu z}]dA-\oint_\infty[\frac{\tilde{\varepsilon}}{\varepsilon}(\boldsymbol{h}_{\nu t}^*\times\boldsymbol{e}_{\mu z})]\cdot dl+\iint_\infty(\nabla_t\frac{\tilde{\varepsilon}}{\varepsilon})\cdot[(\boldsymbol{h}_{\nu t}^*\times\boldsymbol{e}_{\mu z})]dA-j\omega\iint_\infty\frac{\tilde{\varepsilon}}{\varepsilon}\varepsilon_0\boldsymbol{e}_{\nu z}^*\cdot\boldsymbol{e}_{\mu z}dA=-\iint_\infty\frac{\tilde{\varepsilon}}{\varepsilon\varepsilon_0}(\nabla_t\varepsilon_0)\cdot(\boldsymbol{h}_{\nu t}^*\times\boldsymbol{e}_{\mu z}]dA+\iint_\infty(\frac{\nabla_t\tilde{\varepsilon}}{\varepsilon}-\frac{\tilde{\varepsilon}\nabla_t\varepsilon}{\varepsilon^2})\cdot[(\boldsymbol{h}_{\nu t}^*\times\boldsymbol{e}_{\mu z})]\cdot dA-j\omega\iint_\infty\frac{\tilde{\varepsilon}}{\varepsilon}\varepsilon_0\boldsymbol{e}_{\nu z}^*\cdot\boldsymbol{e}_{\mu z}dA \quad (10)$$

式中利用了在无穷横截面上积分时，$\oint_\infty[\frac{\tilde{\varepsilon}}{\varepsilon}(\boldsymbol{h}_{\nu t}^*\times\boldsymbol{e}_{\mu z})]\cdot dl=0$

式(9)右边第二式可化为

$$\iint_\mu\boldsymbol{h}_{\nu t}^*\cdot\frac{1}{\varepsilon}[(\nabla_t\varepsilon)\times(\frac{\varepsilon_0}{\varepsilon}\boldsymbol{e}_{\mu z})]dA=-\iint_\infty\frac{\varepsilon_0}{\varepsilon^2}[(\nabla_t\varepsilon)\cdot(\boldsymbol{h}_{\nu t}^*\times\boldsymbol{e}_{\mu z})]dA \quad (11)$$

从而可以得到严格的非正交矢量耦合波方程

$$\sum_\mu\boldsymbol{P}_{\mu\nu}\frac{da_\mu}{dz}=\sum_\mu\boldsymbol{H}_{\mu\nu}b_\mu \quad (12)$$

式中

$$\boldsymbol{H}_{\mu\nu}=j\boldsymbol{P}_{\mu\nu}\beta_\mu+\boldsymbol{K}_{\mu\nu}^{(1)}\quad \boldsymbol{P}_{\mu\nu}=\iint_\infty(\boldsymbol{e}_{\mu t}\times\boldsymbol{h}_{\nu t}^*)\cdot\hat{z}dA \quad (13)$$

$$\boldsymbol{K}_{\mu\nu}^{(1)}=-\iint_\infty\frac{\tilde{\varepsilon}}{\varepsilon\varepsilon_0}(\nabla_t\varepsilon_0)\cdot(\boldsymbol{h}_{\nu t}^*\times\boldsymbol{e}_{\mu z})dA+\iint(\frac{\nabla_t\tilde{\varepsilon}}{\varepsilon}-\frac{\tilde{\varepsilon}\nabla_t\varepsilon}{\varepsilon^2})\cdot[(\boldsymbol{h}_{\nu t}^*\times\boldsymbol{e}_{\mu z})]dA-j\omega\iint_\infty\frac{\varepsilon_0}{\varepsilon}\tilde{\varepsilon}\boldsymbol{e}_{\nu z}\cdot\boldsymbol{e}_{\mu z}dA-\iint_\infty\frac{\varepsilon_0}{\varepsilon^2}[(\nabla_t\varepsilon)\cdot(\boldsymbol{h}_{\nu t}^*\times\boldsymbol{e}_{\mu z})]dA+\iint_\infty\frac{1}{\varepsilon_0}[\nabla_t\varepsilon_0\cdot(\boldsymbol{h}_{\nu t}^*\times\boldsymbol{e}_{\mu z})]dA=-j\omega\iint_\infty\frac{\varepsilon_0}{\varepsilon}\tilde{\varepsilon}\boldsymbol{e}_{\nu z}\cdot\boldsymbol{e}_{\mu z}dA+\iint_\infty(\frac{1}{\varepsilon_0}-\frac{\tilde{\varepsilon}}{\varepsilon\varepsilon_0})(\nabla_t\varepsilon_0)\cdot(\boldsymbol{h}_{\nu t}^*\times\boldsymbol{e}_{\mu z})dA-\iint_\infty\frac{\nabla_t\varepsilon_0}{\varepsilon}[(\boldsymbol{h}_{\nu t}^*\times\boldsymbol{e}_{\mu z})]\cdot dA=-j\omega\iint_\infty\frac{\varepsilon_0}{\varepsilon}\tilde{\varepsilon}\boldsymbol{e}_{\nu z}\cdot\boldsymbol{e}_{\mu z}dA \quad (14)$$

同理，由式(2)可得

$$\sum_\mu\boldsymbol{P}_{\mu\nu}\frac{db_\mu}{dz}=\sum_\mu\boldsymbol{F}_{\mu\nu}a_\mu \quad (15)$$

式中

$$\boldsymbol{F}_{\mu\nu}=j\boldsymbol{P}_{\mu\nu}\beta_\mu+\boldsymbol{K}_{\mu\nu}^{(2)}\quad \boldsymbol{K}_{\mu\nu}^{(2)}=-j\omega\varepsilon_0\iint_\infty\tilde{\varepsilon}\boldsymbol{e}_{\nu t}^*\cdot\boldsymbol{e}_{\mu t}dA \quad (16)$$

这时发现在耦合系数的表达式中并不存在偏振耦合项，而且在以上的推导过程中没有用到任何近似，适合于各向同性光波导受到各向同微扰时的任意情况下的耦合，从耦合系数 $\boldsymbol{K}_{\mu\nu}^{(1)}$ 可以看出，所得到的耦合波方程可以分析微扰光波导的纵向耦合．现把以上矢量理论弱导近似，忽略所有的二阶小量，并把 $a_\mu(z)$ 分解为缓变部分 $c_\mu(z)$ 和迅变部分 $\exp(j\beta_\mu z)$ 之积，即

$$a_\mu(z)=c_\mu(z)\exp(j\beta_\mu z) \quad (17)$$

则

$$\frac{\mathrm{d}^2 a_\mu}{\mathrm{d}z^2}\approx(2\mathrm{j}\beta_\mu\frac{\mathrm{d}c_\mu}{\mathrm{d}z}-\beta_\mu^2 c_\mu)\exp(\mathrm{j}\beta_\mu z) \tag{18}$$

在式(18),忽略了二阶缓变量$\frac{\mathrm{d}^2 c_\mu}{\mathrm{d}z^2}$,这意味着纵向非均匀性$\varepsilon(z)$是缓变的,即$\frac{\lambda\partial\varepsilon}{\varepsilon\partial z}\to 0$. 对式(12)两边求导并把式(15)代入,再由式(17)和式(18)可得

$$\sum_\mu\frac{\mathrm{d}c_\mu(z)}{\mathrm{d}z}=\sum_\mu \boldsymbol{K}_{\mu\nu}c_\mu(z) \tag{19}$$

式中

$$\boldsymbol{K}_{\mu\nu}=\frac{\boldsymbol{K}_{\mu\nu}^{(1)}+\boldsymbol{K}_{\mu\nu}^{(2)}}{2\boldsymbol{P}_{\mu\nu}} \tag{20}$$

如对上述理论做弱导近似，则横电场和横磁场的二阶导数可被忽略，且$\frac{\nabla_t\varepsilon_0}{\beta\varepsilon_0}\approx 0$,由式(6)可知

$$\boldsymbol{h}_{\nu t}^*=\frac{\beta}{\omega\mu_0}(\hat{z}\times\boldsymbol{e}_{\nu t}^*) \tag{21}$$

从式(21)和$\nabla_t\times\boldsymbol{h}_t=-\mathrm{j}\omega\varepsilon_0\boldsymbol{e}_z$ 可得到

$$\boldsymbol{e}_{\mu z}=\frac{\mathrm{j}}{\beta}(\nabla_t\cdot\boldsymbol{e}_{\mu t})\hat{z} \tag{22}$$

由式(22)可见 $\boldsymbol{e}_{\mu z}$是一阶小量,从而 $\boldsymbol{K}_{\mu\nu}^{(1)}=0$. 把式(21)代入式(13)可得

$$\boldsymbol{P}_{\mu\nu}=\iint_\infty\frac{\beta}{\omega\mu_0}[\boldsymbol{e}_{\mu t}\times(\hat{z}\times\boldsymbol{e}_{\nu t}^*)]\cdot\hat{z}\mathrm{d}A=\iint_\infty-\frac{\beta}{\omega\mu_0}[(\boldsymbol{e}_{\mu t}\cdot\hat{z})\boldsymbol{e}_{\nu t}^*-(\boldsymbol{e}_{\mu t}\cdot\boldsymbol{e}_{\nu t}^*)\hat{z}]\cdot\hat{z}\mathrm{d}A=\iint_\infty\frac{\beta}{\omega\mu_0}\boldsymbol{e}_{\mu t}\cdot\boldsymbol{e}_{\nu t}^*\mathrm{d}A \tag{23}$$

这时由式(19)和式(20)可得所熟悉的弱导缓变近似下的非正交耦合波方程和耦合系数表达式为[15]

$$\sum_\mu\frac{\mathrm{d}c_\mu(z)}{\mathrm{d}z}=\sum_\mu \boldsymbol{K}_{\mu\nu}c_\mu(z) \tag{24}$$

式中

$$\boldsymbol{K}_{\mu\nu}=\frac{\boldsymbol{K}_{\mu\nu}^{(2)}}{2\boldsymbol{P}_{\mu\nu}}=\mathrm{j}\frac{-k^2\iint_\infty\tilde{\varepsilon}\boldsymbol{e}_{\nu t}^*\cdot\boldsymbol{e}_{\mu t}\mathrm{d}A}{2\beta_\nu\iint_\infty\boldsymbol{e}_{\mu t}\cdot\boldsymbol{e}_{\nu t}^*\mathrm{d}A} \tag{25}$$

2 讨论

对各向同性光波导受到各向同性微扰时，严格的非正交矢量耦合模理论所得到的耦合系数表达式与 Wei-Ping Huang 的理论相比少了一项偏振耦合项．而且在弱导时 $\boldsymbol{K}_{\mu\nu}^{(1)}$ 的表达式中的第一个等式中的第四项可化为

$$-\iint_\infty\frac{\varepsilon_0}{\varepsilon^2}[(\nabla_t\varepsilon)\cdot(\boldsymbol{h}_{\nu t}^*\times\boldsymbol{e}_{\mu z}]=-\iint_\infty\frac{\varepsilon_0}{\varepsilon^2}(\nabla_t\tilde{\varepsilon})\cdot[\frac{\beta}{\omega\mu_0}(\hat{z}\times\boldsymbol{e}_{\nu t}^*)\times\frac{\mathrm{j}}{\beta}(\nabla_t\cdot\boldsymbol{e}_{\mu t})\hat{z}]\mathrm{d}A=-\iint_\infty\mathrm{j}\frac{1}{\omega\mu_0}\cdot\frac{\varepsilon_0}{\varepsilon^2}(\nabla_t\tilde{\varepsilon})\cdot[(\hat{z}\times\boldsymbol{e}_{\nu t}^*)\times(\nabla_t\cdot\boldsymbol{e}_{\mu t})\hat{z}]\mathrm{d}A=-\iint_\infty\mathrm{j}\frac{1}{\omega\mu_0}\cdot\frac{\varepsilon_0}{\varepsilon^2}(\nabla_t\tilde{\varepsilon})\cdot[\boldsymbol{e}_{\nu t}^*(\nabla_t\cdot\boldsymbol{e}_{\mu t})\hat{z}\cdot\hat{z})-(\nabla_t\cdot\boldsymbol{e}_{\mu t})\hat{z}\cdot\boldsymbol{e}_{\nu t}^*)\hat{z}]\mathrm{d}A=-\iint_\infty\mathrm{j}\frac{1}{\omega\mu_0}\frac{\varepsilon_0}{\varepsilon^2}\boldsymbol{e}_{\nu t}^*\cdot(\nabla_t\tilde{\varepsilon})(\nabla_t\cdot\boldsymbol{e}_{\mu t})\mathrm{d}A \tag{26}$$

式(26)近似于文献[11]中所定义的偏振耦合项：$-\int(\nabla_t\cdot\boldsymbol{e}_{tp}^*)(\nabla_t\mathrm{In}n^2\cdot\boldsymbol{e}_{tq})\mathrm{d}a$.

3 结论

由分析可知，Wei-Ping Huang 理论中的偏振耦合项在严格的矢量理论推导过程中出现过，但它与弱导近似中所忽略的项相抵消．从耦合系数式(25)可以看出，弱导近似下的各向同性光波导受各向同性微扰时两正交线偏振模之间不产生耦合，即 $\boldsymbol{e}_{\nu t}^*$ 与 $\boldsymbol{e}_{\mu t}$ 方向正交时，$k^2\iint_\infty\tilde{\varepsilon}\boldsymbol{e}_{\nu t}^*\cdot\boldsymbol{e}_{\mu t}\mathrm{d}A=0$，并不存在偏振耦合项对耦合的贡献[11].

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The Rigorous Vectorial Coupled-Mode Theory for the Isotropic Optical Waveguide with Isotropic Disturbances

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Abstract The rigorous nonorthogonal vectorial coupled-mode theory is presented for the isotropic waveguide with isotropic disturbances, based on the Maxwell Equation. The coupling term due to polarization, which is presented in the scalar coupled-mode theory with the vector correction of the Wei-Ping Huang, isn't included in this rigorous vectorial coupled-mode theory, and the term is emerged during the derivation. It is because that the coupling term due to polarization and the ignored term due to the weakly guiding approximation are as small as the second order, and they are just the same. Therefore, the rigorous vectorial coupled-mode theory has not the coupling term due to polarization which can be looked as the vector correction for the scalar coupled-mode theory.

Keywords Optical waveguide; Vectorial coupled-mode theory; Coupling term due to polarization; Maxwell equation

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