大作业二

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1. 模型构建

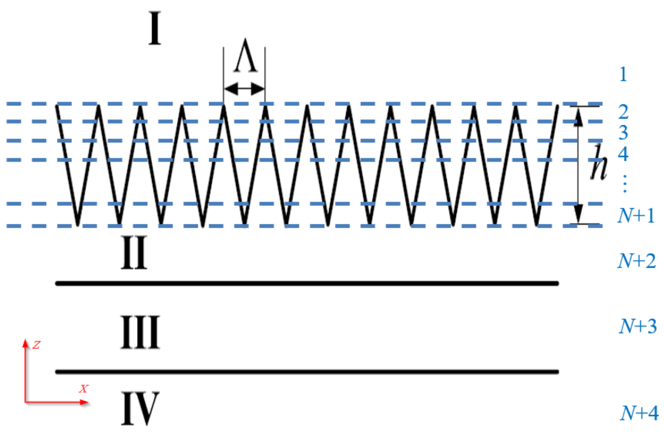

图 1　　四层平行波导的分层标记

如图 1 所示，把光栅均匀分成 N 层，每一层的高度为 $\Delta h = h/N$ 。以阿拉伯数字标记所有的层，原来的第 I 层记为第 1 层，光栅的 N 层沿 z 轴反方向依次记为第 2、3、……、N+1 层，没有光栅的第 II 层、第III 和 IV 层依次记为第 N+2 、 N+3 和 N+4 层。

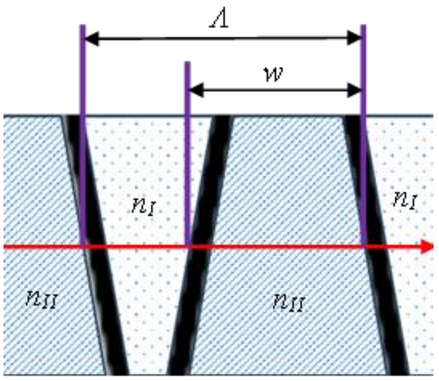

图 2　　光栅空间内，第 i 层 $(2 \le i \le N+1)$ 的结构

考察第 i 层 $(1 \le i \le N+4)$ 的均方折射率 $\tilde{n_\iota}$ ：对于第 1 、 N+2 、 N+3 和 N+4 层来说，平均折射率就是层内折射率 n_I 、 n_{II} 、n_{IiI} 和 n_{IV} ；对于第i 层 $(2 \le i \le N+3)$ 来说，需要利用平分面进行近似计算。如图 2 所示，红线代表层间的厚度等分面，等分面与第 II 层相交宽度是 w ，那么记第 i 层的均方折射率为等分面内的均方折射率，即

$$\widetilde{n_i}=\sqrt{\frac{1}{\Lambda}\int_{\Lambda} n(x,z)^2dz\bigg|_{x=midline}}=\sqrt{\frac{1}{\Lambda}[n_I^2(\Lambda-w_i)+n_{II}^2w_i]}=\sqrt{n_i^2+\frac{(n_{II}^2-n_I^2)w_i}{\Lambda}} \tag{1.1}$$

同时利用三角形相似的几何关系可以算出 $w_i=\frac{i-3/2}{N}\Lambda$，结合 (1.1) 式可得

$$\widetilde{n_i}=\begin{cases}\sqrt{n_i^2+\frac{(n_{II}^2-n_I^2)(i-3/2)}{N}} & i=2,3,\cdots,N+1\\ n_I & 1\\ n_{II} & N+2\\ n_{III} & N+3\\ n_{IV} & N+4\end{cases} \tag{1.2}$$

对于第 i 层平行波导，利用 TE 模式的电场波动方程可知

$$E_i(x,z)=E_{y,i}(x,z)=E_{y,i}(x)e^{-ik_0n_{eff}z} \tag{1.3}$$

$$\frac{d^2E_{y,i}(x)}{dx^2}+k_0^2\left(\widetilde{n_i}^2-n_{eff}{}^2\right)E_{y,i}(x)=0 \tag{1.4}$$

为了保持 $E_{y,i}(x)$ 的表达式在实数域内运算，所以构建表达式为

$$E_{y,i}(x)=\begin{cases}B_1e^{-\gamma_1(x-x_1)} & i=1\\ A_{N+4}e^{\gamma_{N+4}(x-x_{N+3})} & i=N+4\\ A_i\cos[\kappa_i(x-x_i)]+B_i\sin[\kappa_i(x-x_i)] & 2\le i\le N+3, n_{eff}<\widetilde{n_i}\\ A_i\cosh[\gamma_i(x-x_i)]+B_i\sinh[\gamma_i(x-x_i)] & 2\le i\le N+3, n_{eff}>\widetilde{n_i}\end{cases} \tag{1.5}$$

其中 $\gamma_i=j\kappa_i=j\sqrt{\widetilde{n_i}^2-n_{eff}^2}$，$x_i$ 是第 i 层底部的 x 坐标。

那么磁场强度$H_{y,i}(x)$ 的表达式也可以写成

$$H_{y,i}(x)=\begin{cases}-\gamma_1B_1e^{-\gamma_1(x-x_1)} & i=1\\ \gamma_{N+4}A_{N+4}e^{\gamma_{N+4}(x-x_{N+3})} & i=N+4\\ -\kappa_i\{A_i\cos[\kappa_i(x-x_i)]-B_i\sin[\kappa_i(x-x_i)]\} & 2\le i\le N+3, n_{eff}<\widetilde{n_i}\\ \gamma_i\{A_i\sinh[\gamma_i(x-x_i)]+B_i\cosh[\gamma_i(x-x_i)]\} & 2\le i\le N+3, n_{eff}>\widetilde{n_i}\end{cases} \tag{1.6}$$

其中 n_{eff} 是有效折射率。记 i_0 是满足 $\widetilde{n_{i_0}}<n_{eff}<\widetilde{n_{i_0+1}}$ 的最小下标，结合切向分量连续，那么可以按照 i_0 分成四种情况：

情况一　$i_0=1$

$$\begin{bmatrix}A_2/B_1\\B_2/B_1\end{bmatrix}=\begin{bmatrix}\cos(\kappa_2\Delta h) & -\sin(\kappa_2\Delta h)\\ \sin(\kappa_2\Delta h) & \cos(\kappa_2\Delta h)\end{bmatrix}\begin{bmatrix}1 & 0\\ 0 & -\frac{\gamma_1}{\kappa_2}\end{bmatrix}\begin{bmatrix}1\\1\end{bmatrix} \tag{1.7.1}$$

$$\begin{bmatrix}A_{i+1}/B_1\\B_{i+1}/B_1\end{bmatrix}=\begin{bmatrix}\cos(\kappa_{i+1}\Delta h) & -\sin(\kappa_{i+1}\Delta h)\\ \sin(\kappa_{i+1}\Delta h) & \cos(\kappa_{i+1}\Delta h)\end{bmatrix}\begin{bmatrix}1 & 0\\ 0 & \frac{\kappa_i}{\kappa_{i+1}}\end{bmatrix}\begin{bmatrix}A_i/B_1\\B_i/B_1\end{bmatrix}, 2\le i\le N \tag{1.7.2}$$

$$\begin{bmatrix}A_{N+2}/B_1\\B_{N+2}/B_1\end{bmatrix}=\begin{bmatrix}\cos[\kappa_{N+2}(t_{II}-h)] & -\sin[\kappa_{N+2}(t_{II}-h)]\\ \sin[\kappa_{N+2}(t_{II}-h)] & \cos[\kappa_{N+2}(t_{II}-h)]\end{bmatrix}\begin{bmatrix}1 & 0\\ 0 & \frac{\kappa_{N+1}}{\kappa_{N+2}}\end{bmatrix}\begin{bmatrix}A_{N+1}/B_1\\B_{N+1}/B_1\end{bmatrix} \tag{1.7.3}$$

$$\begin{bmatrix} A_{N+3}/B_1 \\ B_{N+3}/B_1 \end{bmatrix} = \begin{bmatrix} \cos(\kappa_{N+3}t_{III}) & -\sin(\kappa_{N+3}t_{III}) \\ \sin(\kappa_{N+3}t_{III}) & \cos(\kappa_{N+3}t_{III}) \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & \dfrac{\kappa_{N+2}}{\kappa_{N+3}} \end{bmatrix} \begin{bmatrix} A_{N+2}/B_1 \\ B_{N+2}/B_1 \end{bmatrix} \tag{1.7.4}$$

$$\gamma_{N+4}A_{N+3} - \kappa_{N+3}B_{N+3} = 0 \tag{1.7.5}$$

情况二　$2 \leqslant i_0 \leqslant N$

$$\begin{bmatrix} A_2/B_1 \\ B_2/B_1 \end{bmatrix} = \begin{bmatrix} \cosh(\gamma_2\Delta h) & -\sinh(\gamma_2\Delta h) \\ -\sinh(\gamma_2\Delta h) & \cosh(\gamma_2\Delta h) \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & -\dfrac{\gamma_1}{\gamma_2} \end{bmatrix} \begin{bmatrix} 1 \\ 1 \end{bmatrix} \tag{1.8.1}$$

$$\begin{bmatrix} A_{i+1}/B_1 \\ B_{i+1}/B_1 \end{bmatrix} = \begin{bmatrix} \cosh(\gamma_{i+1}\Delta h) & -\sinh(\gamma_{i+1}\Delta h) \\ -\sinh(\gamma_{i+1}\Delta h) & \cosh(\gamma_{i+1}\Delta h) \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & \dfrac{\gamma_i}{\gamma_{i+1}} \end{bmatrix} \begin{bmatrix} A_i/B_1 \\ B_i/B_1 \end{bmatrix}, 2 \le i \le i_0 - 1 \tag{1.8.2}$$

$$\begin{bmatrix} A_{i_0+1}/B_1 \\ B_{i_0+1}/B_1 \end{bmatrix} = \begin{bmatrix} \cos(\kappa_{i_0+1}\Delta h) & -\sin(\kappa_{i_0+1}\Delta h) \\ \sin(\kappa_{i_0+1}\Delta h) & \cos(\kappa_{i_0+1}\Delta h) \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & -\dfrac{\gamma_{i_0}}{\kappa_{i_0+1}} \end{bmatrix} \begin{bmatrix} A_{i_0}/B_1 \\ B_{i_0}/B_1 \end{bmatrix} \tag{1.8.3}$$

$$\begin{bmatrix} A_{i+1}/B_1 \\ B_{i+1}/B_1 \end{bmatrix} = \begin{bmatrix} \cos(\kappa_{i+1}\Delta h) & -\sin(\kappa_{i+1}\Delta h) \\ \sin(\kappa_{i+1}\Delta h) & \cos(\kappa_{i+1}\Delta h) \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & \dfrac{\kappa_i}{\kappa_{i+1}} \end{bmatrix} \begin{bmatrix} A_i/B_1 \\ B_i/B_1 \end{bmatrix}, i_0 + 1 \le i \le N \tag{1.8.4}$$

【同 (1.7.3) 、 (1.7.4) 和 (1.7.5)】	(1.8.5)

情况三　$i_0 = N+1$

$$\begin{bmatrix} A_{i+1}/B_1 \\ B_{i+1}/B_1 \end{bmatrix} = \begin{bmatrix} \cosh(\gamma_{i+1}\Delta h) & -\sinh(\gamma_{i+1}\Delta h) \\ -\sinh(\gamma_{i+1}\Delta h) & \cosh(\gamma_{i+1}\Delta h) \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & \dfrac{\gamma_i}{\gamma_{i+1}} \end{bmatrix} \begin{bmatrix} A_i/B_1 \\ B_i/B_1 \end{bmatrix}, 2 \le i \le N \tag{1.9.1}$$

$$\begin{bmatrix} A_{N+2}/B_1 \\ B_{N+2}/B_1 \end{bmatrix} = \begin{bmatrix} \cos[\kappa_{N+2}(t_{II} - h)] & -\sin[\kappa_{N+2}(t_{II} - h)] \\ \sin[\kappa_{N+2}(t_{II} - h)] & \cos[\kappa_{N+2}(t_{II} - h)] \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & \dfrac{\gamma_{N+1}}{\kappa_{N+2}} \end{bmatrix} \begin{bmatrix} A_{N+1}/B_1 \\ B_{N+1}/B_1 \end{bmatrix} \tag{1.9.2}$$

【同 (1.8.1) 、 (1.7.4) 和 (1.7.5)】	(1.9.3)

情况四　$i_0 = N+2$

$$\begin{bmatrix} A_{N+2}/B_1 \\ B_{N+2}/B_1 \end{bmatrix} = \begin{bmatrix} \cosh[\gamma_{N+2}(t_{II} - h)] & -\sinh[\gamma_{N+2}(t_{II} - h)] \\ -\sinh[\gamma_{N+2}(t_{II} - h)] & \cosh[\gamma_{N+2}(t_{II} - h)] \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & \dfrac{\gamma_{N+1}}{\gamma_{N+2}} \end{bmatrix} \begin{bmatrix} A_{N+1}/B_1 \\ B_{N+2}/B_1 \end{bmatrix} \tag{1.10.1}$$

$$\begin{bmatrix} A_{N+3}/B_1 \\ B_{N+3}/B_1 \end{bmatrix} = \begin{bmatrix} \cos(\kappa_{N+3}t_{III}) & -\sin(\kappa_{N+3}t_{III}) \\ \sin(\kappa_{N+3}t_{III}) & \cos(\kappa_{N+3}t_{III}) \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & \dfrac{\gamma_{N+2}}{\kappa_{N+3}} \end{bmatrix} \begin{bmatrix} A_{N+2}/B_1 \\ B_{N+2}/B_1 \end{bmatrix} \tag{1.10.2}$$

【同 (1.8.1) 、 (1.9.1) 和 (1.7.5)】	(1.10.3)

根据这四种情况，就可以利用 MATLAB 编程计算出 n_{eff} 。

平行波导的折射率在空间上沿 z 轴以 Λ 为周期循环。记 $n(x,z)^2$ 的 m 级 Fourier 展开系数为 $A_m(x)$ 。当 $m > 1$ 时

$$A_m(x) = \frac{1}{\Lambda}\int_{\Lambda} n(x,z)^2 e^{-i\frac{2\pi m}{\Lambda}z} dz = \begin{cases} \dfrac{w(x)}{\Lambda}(n_{II}^2 - n_I^2)\,\mathrm{sinc}\left(\dfrac{\pi m w(x)}{\Lambda}\right) & i = 2,3,\cdots,N+1 \\ 0 & 1, N+2, N+3, N+4 \end{cases} \tag{1.11}$$

其中 $\operatorname{sinc} x = \lim\limits_{t\to x}\frac{\sin t}{t}$，$w(x)/\Lambda = 1 - \frac{x - x_{N+1}}{h}$。

记 $\beta_0=2\pi/\Lambda$，第 m 级展开的光栅的耦合系数 κ_m 为

$$\kappa_m = \frac{k_0^2}{2\beta_0}\frac{\int_{-\infty}^{+\infty} A_m(x)E(x)E^*(x)dx}{\int_{-\infty}^{+\infty} E(x)E^*(x)dx} = \frac{\pi\Lambda}{\lambda^2}\frac{\int_{x_{N+1}}^{x_1} A_m(x)E(x)E^*(x)dx}{\int_{x_{N+1}}^{x_1} E(x)E^*(x)dx} \tag{1.12}$$

2. 有效折射率

让光栅高度 h 在 $[0, 0.1]\mu m$ 内变化，那么 h-n_{eff} 的变化曲线如下图 3：

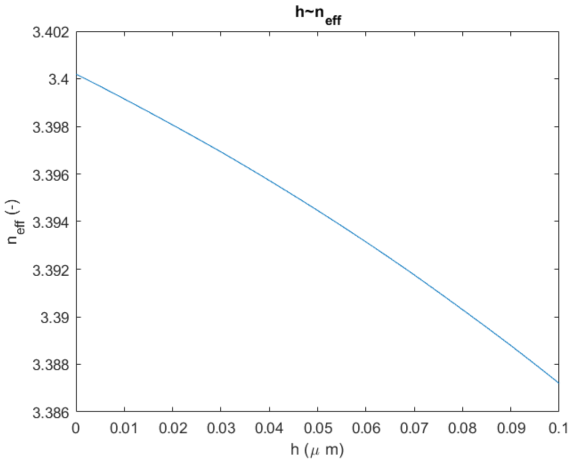

图 3　　有效折射率的变化曲线

当 $h = 0$ 时，计算出来的 $n_{eff} = 3.4002$，与大作业一所计算的 $n_{eff} = 3.4002$ 一致。同时，最小二乘法拟合直线的斜率为 -0.1296 μm^{-1}，截距为 3.4007，累计误差 $\varepsilon = \frac{1}{h}\int_0^{0.1\mu m}\left[n_{eff}(h) - n_{eff,拟合}(h)\right]^2 dh \approx 5.3182 \times 10^{-8}$。

3. 耦合系数

让光栅高度 h 在 [0, 0.1]μm 内变化，取 $m = 2$，那么 h-κ_m 的变化曲线如下图 3：

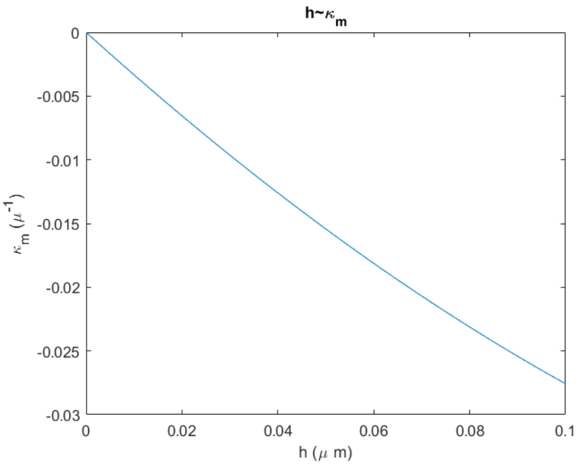

图 4　　耦合系数的变化曲线

最小二乘法拟合直线的斜率为 -0.2760 μm^{-2}，截距为 -0.0011 μm^{-1}，累计误差 $\varepsilon = \frac{1}{h}\int_0^{0.1\mu m}\left[\kappa_m(h) - \kappa_{m,拟合}(h)\right]^2 dh \approx 2.4194 \times 10^{-7} \mu m^{-2}$。

4. 附录

以下附上本次作业中所用到的代码

代码名称：hneff.m	作用：计算每一个 h 下的 n_{eff} 和 κ_m

```
function [NEFF,km] = hneff(nI,nII,nIII,nIV,tII,tIII,h,Lambda,N,lambda)
% Calculate the relationship between h and neff
%   Detailed explanation goes here
%=========每层的实际折射率以及厚度=========

%=========每层的实际折射率=========

%=========光栅参数以及每层的等效折射率=========
n_layer_eff = zeros(N,1);
for i = 1:N
    n_layer_eff(i)=sqrt((i-0.5)/N*nII^2+(1-(i-0.5)/N)*nI^2);
end
n_layer_eff=[nI;n_layer_eff;nII;nIII;nIV];
%=========光栅参数以及每层的等效折射率=========

%=========入射光波长及真空波矢=========
k0 = 2*pi/lambda; %真空波矢
%=========入射光波长及真空波矢=========

%=========有效折射率搜寻范围及 kappa 参数计算=========
neff = [];
dn = 1e-3;
for i=1:N+2
    neff = [neff n_layer_eff(i)+dn:dn:n_layer_eff(i+1)-dn];
end
NUMNEFF = length(neff);
neff = neff';
f = zeros(1,NUMNEFF);
for i=1:NUMNEFF
    i0 = find(n_layer_eff>neff(i),1,"first")-1;
    kappa = k0*sqrt(n_layer_eff.^2-neff(i)^2);
    gamma = [-1i*kappa(1:i0);zeros(N+3-i0,1);-1i*kappa(N+4)];
    kappa = [zeros(i0,1);kappa(i0+1:N+3);0];
    B = zeros(N+3,2);
    B(1,:) = [1 1];
    if i0 < N+1
        if i0 == 1
            B(2,:) = (rotmatrix(kappa(2)*dh)*diag([1,-
gamma(1)/kappa(2)])*B(1,:)')';
        else
            B(2,:) = (rotmatrix_h(gamma(2)*dh)*diag([1 -
gamma(1)/gamma(2)])*B(1,:)')';
            for j = 2:i0-1
                B(j+1,:) = (rotmatrix_h(gamma(j+1)*dh)*diag([1
gamma(j)/gamma(j+1)])*B(j,:)')';
            end
            B(i0+1,:) = (rotmatrix(kappa(i0+1)*dh)*diag([1
gamma(i0)/kappa(i0+1)])*B(i0,:)')';
        end
        for j=i0+1:N
            B(j+1,:) = (rotmatrix(kappa(j+1)*dh)*diag([1
kappa(j)/kappa(j+1)])*B(j,:)')';
```

```
        end
        B(N+2,:) = (rotmatrix(kappa(N+2)*(tII-h))*diag([1
kappa(N+1)/kappa(N+2)])*B(N+1,:)');
        B(N+3,:) = (rotmatrix(kappa(N+3)*tIII)*diag([1
kappa(N+2)/kappa(N+3)])*B(N+2,:)')';
    else
        B(2,:) = (rotmatrix_h(gamma(2)*dh)*diag([1 -gamma(1)/gamma(2)])*B(1,:)')';
        for j = 2:N
            B(j+1,:) = (rotmatrix_h(gamma(j+1)*dh)*diag([1
gamma(j)/gamma(j+1)])*B(j,:))';
        end
        if i0 == N+1
            B(N+2,:) = (rotmatrix(kappa(N+2)*(tII-h))*diag([1
gamma(N+1)/kappa(N+2)])*B(N+1,:)')';
            B(N+3,:) = (rotmatrix(kappa(N+3)*tIII)*diag([1
kappa(N+2)/kappa(N+3)])*B(N+2,:)')';
        else
            B(N+2,:) = (rotmatrix_h(gamma(N+2)*(tII-h))*diag([1
gamma(N+1)/gamma(N+2)])*B(N+1,:)')';
            B(N+3,:) = (rotmatrix(kappa(N+3)*tIII)*diag([1
gamma(N+2)/kappa(N+3)])*B(N+2,:)')';
        end
    end
    f(i) = gamma(N+4)*B(N+3,1)-kappa(N+3)*B(N+3,2);
    if i > 1
        if f(i)*f(i-1) <= 0
            l1 = -f(i)/(f(i-1)-f(i));
            l0 = f(i-1)/(f(i-1)-f(i));
            NEFF = l1*neff(i-1)+l0*neff(i);

            m = 2;
            Nh = 100;
            ddh = dh/Nh;
            xr = linspace(0,dh,Nh+1);
            i0 = find(n_layer_eff(1:N+1)>NEFF,1,"first")-1;
            % i0 = 1;
            kappa = k0*sqrt(n_layer_eff(1:N+1).^2-NEFF^2);
            gamma = [-1i*kappa(1:i0);zeros(N+1-i0,1)];
            kappa = [zeros(i0,1);kappa(i0+1:N+1)];

            if i0 == 1
                B(2,:) = (rotmatrix(kappa(2)*dh)*diag([1,-
gamma(1)/kappa(2)])*B(1,:)')';
                Ey = B(2,:)*[cos(kappa(2)*xr);sin(kappa(2)*xr)];
                x = h-(2-1)*dh+xr;
                w = (1-x/h)*Lambda;
                Am = w/Lambda*(nII^2-nI^2).*sinc(pi*m*w/Lambda);
                AEE = Ey*diag(Am)*conj(Ey)'*ddh;
                P = Ey*conj(Ey)'*ddh;
            else
                B(2,:) = (rotmatrix_h(gamma(2)*dh)*diag([1 -
gamma(1)/gamma(2)])*B(1,:)')';
                Ey = B(2,:)*[cosh(gamma(2)*xr);sinh(gamma(2)*xr)];
                x = h-(2-1)*dh+xr;
                w = (1-x/h)*Lambda;
                Am = w/Lambda*(nII^2-nI^2).*sinc(pi*m*w/Lambda);
                AEE = Ey*diag(Am)*conj(Ey)'*ddh;
                P = Ey*conj(Ey)'*ddh;
```

```
                for j = 2:i0-1
                    B(j+1,:) = (rotmatrix_h(gamma(j+1)*dh)*diag([1 
gamma(j)/gamma(j+1)])*B(j,:)')';
                    Ey = B(j+1,:)*[cosh(gamma(j+1)*xr);sinh(gamma(j+1)*xr)];
                    x = h-j*dh+xr;
                    w = (1-x/h)*Lambda;
                    Am = w/Lambda*(nII^2-nI^2).*sinc(pi*m*w/Lambda);
                    AEE = AEE+Ey*diag(Am)*conj(Ey)'*ddh;
                    P = P+Ey*conj(Ey)'*ddh;
                end

                if i0 < N+1
                    B(i0+1,:) = (rotmatrix(kappa(i0+1)*dh)*diag([1 
gamma(i0)/kappa(i0+1)])*B(i0,:)')';
                    Ey = B(i0+1,:)*[cos(kappa(i0+1)*xr);sin(kappa(i0+1)*xr)];
                    x = h-i0*dh+xr;
                    w = (1-x/h)*Lambda;
                    Am = w/Lambda*(nII^2-nI^2).*sinc(pi*m*w/Lambda);
                    AEE = AEE+Ey*diag(Am)*conj(Ey)'*ddh;
                    P = P+Ey*conj(Ey)'*ddh;
                end
            end
            for j=i0+1:N
                B(j+1,:) = (rotmatrix(kappa(j+1)*dh)*diag([1 
kappa(j)/kappa(j+1)])*B(j,:)')';
                Ey = B(j+1,:)*[cos(kappa(j+1)*xr);sin(kappa(j+1)*xr)];
                x = h-j*dh+xr;
                w = (1-x/h)*Lambda;
                Am = w/Lambda*(nII^2-nI^2).*sinc(pi*m*w/Lambda);
                AEE = AEE+Ey*diag(Am)*conj(Ey)'*ddh;
                P = P+Ey*conj(Ey)'*ddh;
            end
            beta0 = m*pi/Lambda;
            km = k0^2/(2*beta0*P)*AEE;
            break;
        end
    else
        if f(1) == 0
            NEFF = neff(1);
            break;
        end
    end
end

    end
```

代码名称：rotmatrix.m	作用：生成三角旋转矩阵

```
function R = rotmatrix(t)
R=[cos(t) -sin(t);sin(t) cos(t)];
end
```

代码名称：rotmatrixh.m	作用：生成三角余弦旋转矩阵

```
function R = rotmatrix_h(t)
R=[cosh(t) -sinh(t);-sinh(t) cosh(t)];
end
```

代码名称：sinc.m	作用：无极点函数

```
function y = sinc(x)
%sinc Summary of this function goes here
%   Detailed explanation goes here
y = zeros(1,length(x));
for i = 1:length(x)
    if x(i) == 0
        y(i) = 1;
    else
        y(i) = sin(x(i))./x(i);
    end
end
```

代码名称：p1_1.m	作用：生成 main 函数

```
%=========每层的实际折射率以及厚度=========
nI=3.29;tI=inf;
nII=3.45;tII=0.15;
nIII=3.59;tIII=0.1;
nIV=3.29;tIV=inf;
%=========每层的实际折射率=========

%=========光栅参数=========
N1 = 1000;
h = linspace(0,0.1,N1+1); %光栅高度
h = h';
Lambda = 0.25; %光栅周期
N = 20; %光栅分层级数
%=========光栅参数=========

%=========入射光波长=========
lambda=0.88; %0.88um 的入射光
%=========入射光波长=========

NEFF = zeros(N1+1,1);
km = zeros(N1+1,1);
for i=1:N1+1
    [NEFF(i),km(i)]=hneff(nI,nII,nIII,nIV,tII,tIII,h(i),Lambda,N,lambda);
    if isnan(km(i))
        km(i) = 0;
    end
end

A = [h ones(N1+1,1)];
P = inv(A'*A)*A';
coe_NEFF = P*NEFF;
coe_km = P*km;
km_ideal = A*coe_km;
NEFF_ideal = A*coe_NEFF;
err_NEFF = NEFF_ideal-NEFF;
err_km = km_ideal-km;
err_NEFF = err_NEFF'*err_NEFF/(N1+1);
err_km = err_km'*err_km/(N1+1);

figure('Name',"h-neff")
```

```
plot(h,NEFF);
title("h~n_{eff}");
xlabel("h (\mu m)");
ylabel("n_{eff} (-)");

figure('Name',"h-km")
plot(h,km);
title("h~\kappa_{m}");
xlabel("h (\mu m)");
ylabel("\kappa_{m} (\mu^{-1})");
```