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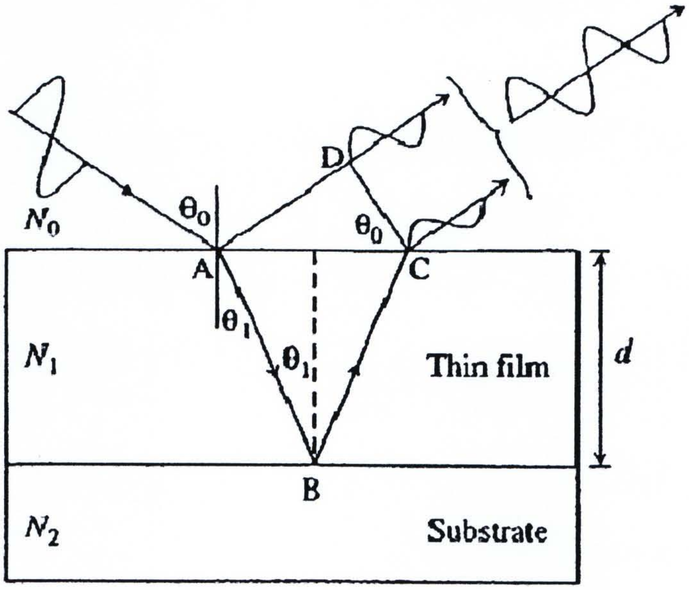
ภาคผนวก

ภาคผนวก ก

การคำนวณการแทรกสอดของแสงในฟิล์มบาง

ก.1 ฟิล์มบางบน Substrate

รูปที่ ก.1 [27] แสดงถึงแบบจำลองของฟิล์มบางที่ปลูกบน Substrate ซึ่งตัวแปรต่าง ๆ แสดงไว้ดังนี้ ค่าคงที่ทางแสงของอากาศ ฟิล์มและ Substrate ตามลำดับซึ่งแสดงอยู่ในรูปของจำนวนเชิงซ้อน (N_0, N_1, N_2) โดยที่ N สามารถเขียนให้อยู่ในลักษณะ n+ik ซึ่ง n คือดรรชนีหักเหและ k คือค่าสัมประสิทธิ์ของการดูดซึม (Extinction coefficient) ความหนาของฟิล์ม (d) และมุมของแสงที่ทำกับเส้นตั้งฉากกับพื้นผิวของฟิล์ม (θ)



รูปที่ ก.1 การแทรกสอดของแสงในฟิล์มบาง [27]

จากเส้นทางเดินของแสงในรูปที่ ก.1 สามารถเขียนเฟสของแสงที่แตกต่างกันระหว่าง $\overline{AD}$ และ $\overline{AC}$ ได้ดังนี้

$$\alpha = \frac{2\pi N_1}{\lambda}\left(\overline{AB} - \overline{BC}\right) - \frac{2\pi N_0}{\lambda}\left(\overline{AD}\right) \qquad \text{--- (ก.1)}$$

ซึ่งจากรูปที่ ก.1 จะเห็นว่า $\overline{AD} = \overline{AC}\, sin(\theta_0)$ และ $\overline{AC} = 2d\, tan(\theta_1)$ ซึ่งจากกฎของ Snell

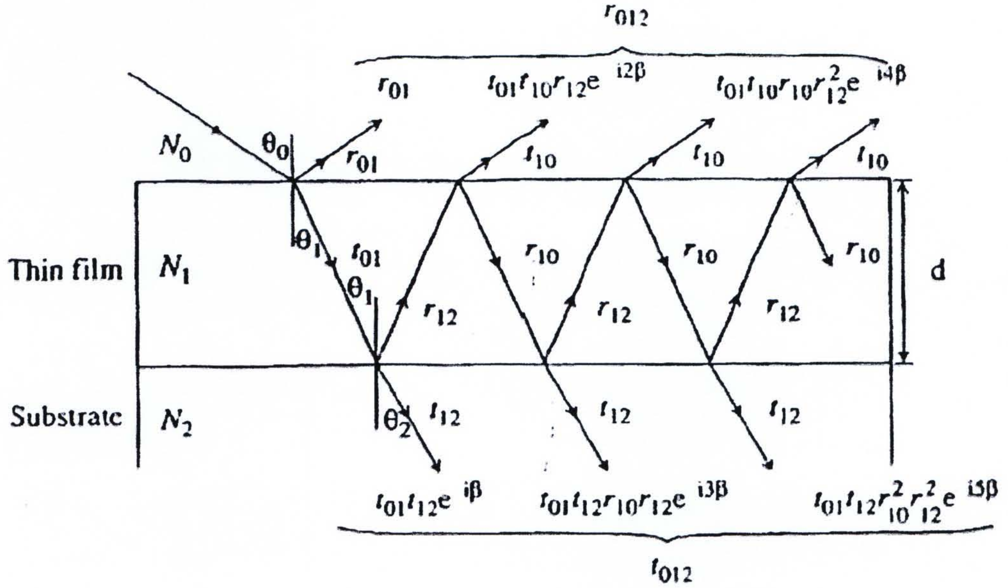
$$\overline{AD} = 2d\frac{sin^2(\theta_1)}{\cos(\theta_1)}\bullet\frac{N_1}{N_0} \quad \text{--- (ก.2)}$$

จากการแทนสมการ (ก.2) ด้วย $\overline{AB} = \overline{BC} = \dfrac{d}{\cos(\theta_1)}$ ในสมการ (ก.1) จะได้

$$\alpha = \frac{4\pi dN_1}{\lambda}\left(\frac{1-sin^2(\theta_1)}{\cos(\theta_1)}\right) = \frac{4\pi dN_1}{\lambda}\cos(\theta_1) = 2\beta \quad \text{--- (ก.3)}$$

ซึ่งสามารถคำนวณเฟสที่แตกต่างกันเนื่องจากความหนาของฟิล์ม (Film phase thickness) ได้จาก

$$\beta = \frac{2\pi d}{\lambda}N_1\cos(\theta_1) = \frac{2\pi d}{\lambda}\left(N_1^2 - N_1^2 sin^2(\theta_0)\right)^{1/2} \quad \text{--- (ก.4)}$$



รูปที่ ก.2 แบบจำลองการแทรกสอดของแสงระหว่างชั้นตัวกลาง อากาศ ฟิล์มบางและ Substrate [27]

จากรูปที่ ก.2 [27] แสดงถึงแบบจำลองการแทรกสอดของแสงระหว่างชั้นตัวกลาง อากาศ ฟิล์มบางและ Substrate ซึ่ง r_{ij} และ t_{ij} แสดงถึงแอมพลิจูดของสัมประสิทธิ์การสะท้อนแสง (Reflection) และการเดินผ่านของแสง (Transmission) ของแต่ละชั้นของตัวกลาง ซึ่งจากสมการของ Fresnel ของ p- และ s-polarization จะได้ว่า

$$r_{ij,p} = \frac{N_j\cos(\theta_i) - N_i\cos(\theta_j)}{N_j\cos(\theta_i) + N_i\cos(\theta_j)} \ , \ r_{ij,s} = \frac{N_i\cos(\theta_i) - N_j\cos(\theta_j)}{N_i\cos(\theta_i) + N_j\cos(\theta_j)} \quad \text{--- (ก.5)}$$

$$t_{ij,p} = \frac{2N_i\cos(\theta_i)}{N_j\cos(\theta_i) + N_i\cos(\theta_j)} \ , \ t_{ij,s} = \frac{2N_i\cos(\theta_i)}{N_i\cos(\theta_i) + N_j\cos(\theta_j)} \quad \text{--- (ก.6)}$$

ซึ่งสามารถคำนวณแอมพลิจูดของสัมประสิทธิ์การสะท้อนของแสงทั้งหมด (r_{012}) ที่สะท้อนออกมาจากแบบจำลองได้จากผลรวมของแสงที่สะท้อนออกมาทุกเส้นได้ดังนี้

$$r_{012} = r_{01} + t_{01}t_{10}r_{12}e^{i2\beta} + t_{01}t_{10}r_{10}r_{12}{}^{2}e^{i4\beta} + t_{01}t_{10}r_{10}{}^{2}r_{12}{}^{3}e^{i6\beta} + \ldots \quad \text{--- (ก.7)}$$

จากอนุกรมอนันต์ $y = a + ar + ar^2 + ar^3 + \ldots$ จะสามารถเขียนให้อยู่ในรูป $y = \frac{a}{1-r}$ ได้ดังนั้นจากสมการที่ (ก.7) จะสามารถเขียนให้อยู่ในรูปอย่างง่ายได้ดังนี้

$$r_{012} = r_{01} + \left[\frac{t_{01}t_{10}r_{12}e^{(2i\beta)}}{1 - r_{10}r_{12}e^{(2i\beta)}}\right] \quad \text{--- (ก.7)}$$

จากความสัมพันธ์ $\mathrm{r}_{10} = -r_{01}$ และ $\mathrm{t}_{01}\mathrm{t}_{10} = 1 - r_{01}^2$ ทำให้สามารถเขียนสมการที่ (ก.7) ให้อยู่ในอยู่ในรูปดังนี้

$$r_{012} = \left[\frac{r_{01} + r_{12}e^{(2i\beta)}}{1 + r_{10}r_{12}e^{(2i\beta)}}\right] \quad \text{--- (ก.8)}$$

ในทำนองเดียวกันก็จะสามารถเขียนสมการของการเดินทางผ่านของแสงจากแบบจำลองได้ดังสมการที่ (ก.9)

$$t_{012} = \left[\frac{t_{01}t_{12}e^{(i\beta)}}{1 + r_{10}r_{12}e^{(2i\beta)}}\right] \quad \text{--- (ก.9)}$$

ซึ่งจากสมการที่ (ก.8) และ (ก.9) แอมพลิจูดของสัมประสิทธิ์การสะท้อนของแสงและการเดินทางผ่านของแสงของแบบจำลองสามารถคำนวณได้จาก

$$r_{012,\mathrm{p}} = \left[\frac{r_{01,p} + r_{12,p}e^{(2i\beta)}}{1 + r_{10,p}r_{12,p}e^{(2i\beta)}}\right] \ , \ r_{012,\mathrm{s}} = \left[\frac{r_{01,s} + r_{12,s}e^{(2i\beta)}}{1 + r_{10,s}r_{12,s}e^{(2i\beta)}}\right] \quad \text{--- (ก.10)}$$

$$t_{012,p} = \left[\frac{t_{01,p}t_{12,p}e^{(i\beta)}}{1+r_{10,p}r_{12,p}e^{(2i\beta)}}\right] \quad , \quad t_{012,s} = \left[\frac{t_{01,s}t_{12,s}e^{(i\beta)}}{1+r_{10,s}r_{12,s}e^{(2i\beta)}}\right] \quad \text{--- (ก.11)}$$

จากสมการที่ (ก.10) และ (ก.11) ทำให้สามารถคำนวณอัตราส่วนความเข้มแสง (ความเข้มแสงที่สะท้อนออกจากแบบจำลองต่อความเข้มแสงที่ตกกระทบกับแบบจำลองได้ดังสมการที่ (ก.12)

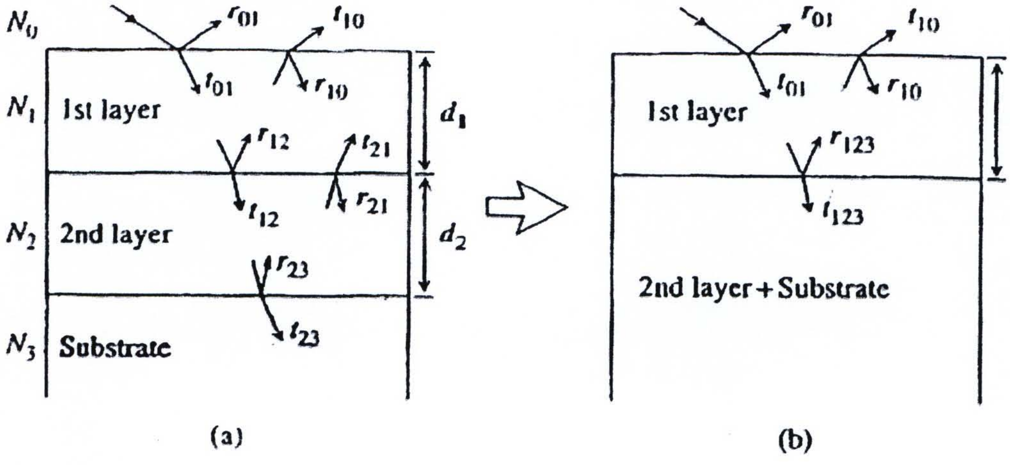
$$\frac{I_{s,p}}{I_{0,p}} = \left|\frac{E_{s,p}}{E_{0,p}}\right|^2 = \left|r_{012,p}\right|^2 \quad , \quad \frac{I_{s,s}}{I_{0,s}} = \left|\frac{E_{s,s}}{E_{0,s}}\right|^2 = \left|r_{012,s}\right|^2 \quad \text{--- (ก.12)}$$

โดยที่มุมตกกระทบและมุมที่แสงเดินทางผ่านชั้นตัวกลางสามารถคำนวณได้จากกฎของ Snell ดังนี้

$$N_0 \sin(\theta_0) = N_1 \sin(\theta_1) = N_2 \sin(\theta_2) \quad \text{--- (ก.13)}$$

ก.2 ฟิล์มหลายชั้นบน Substrate (Multilayers)

การคำนวณการแทรกสอดของแสงในฟิล์มที่มีหลายชั้นสามารถใช้วิธีเดียวกันกับที่ได้อธิบายไปในหัวข้อที่ 1 แล้วจากรูปที่ ก.3 [27] แสดงถึงแบบจำลองของการแทรกสอดของแสงในฟิล์ม 2 ชั้นบน Substrate ซึ่งจะสามารถแบ่งการคำนวณได้ดังที่แสดงไว้ยังรูปที่ ก.3 (b) โดยจะทำการคำนวณฟิล์มชั้นที่ 2 (2nd layer) กับ Substrate ก่อนโดยใช้สมการที่ (ก.8) และ (ก.9) โดยที่มีตัวแปรต่างๆดังที่แสดงไว้ในรูปที่ ก.3



รูปที่ ก.3 วิธีการคำนวณการแทรกสอดของแสงในฟิล์มที่มีหลายชั้น [27]

การคำนวณแอมพลิจูดของสัมประสิทธิ์การสะท้อนของแสงและการเดินทางผ่านของแสงของฟิล์มชั้นที่ 2 กับ Substrate แสดงไว้ยังสมการที่ (ก.14) และ (ก.15)

$$r_{123} = \left[\frac{r_{12} + r_{23}e^{(2i\beta_2)}}{1 + r_{12}r_{23}e^{(2i\beta_2)}}\right] \quad \text{--- (ก.14)}$$

$$t_{123} = \left[\frac{t_{12}t_{23}e^{(i\beta_2)}}{1 + r_{12}r_{23}e^{(2i\beta_2)}}\right] \quad \text{--- (ก.15)}$$

โดยที่การเปลี่ยนแปลงของเฟสของแสงเมื่อเดินทางผ่านชั้นตัวกลางที่ 2 สามารถคำนวณได้ดังนี้

$$\beta_2 = \frac{2\pi d_2 N_2 cos(\theta_2)}{\lambda} \quad \text{--- (ก.16)}$$

จากสมการที่ (ก.14) ถึง (ก.16) สามารถคำนวณแอมพลิจูดของสัมประสิทธิ์การสะท้อนของแสงและการเดินทางผ่านของแสงของแบบจำลองได้ดังนี้

$$r_{0123} = \left[\frac{r_{01} + r_{123}e^{(2i\beta_1)}}{1 + r_{01}r_{123}e^{(2i\beta_1)}}\right] \quad \text{--- (ก.17)}$$

$$t_{0123} = \left[\frac{t_{01}t_{123}e^{(i\beta_1)}}{1 + r_{01}r_{123}e^{(2i\beta_1)}}\right] \quad \text{--- (ก.18)}$$

โดยที่การเปลี่ยนแปลงของเฟสของแสงเมื่อเดินทางผ่านชั้นตัวกลางที่ 1 สามารถคำนวณได้ดังนี้

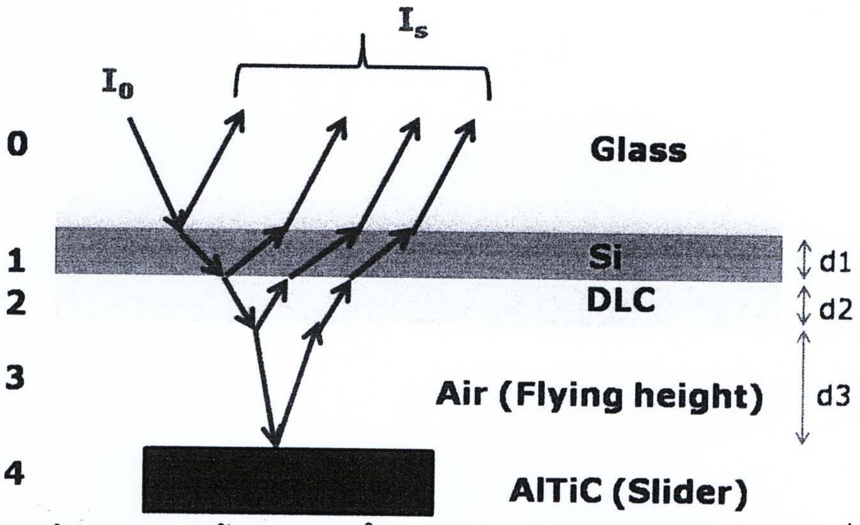
$$\beta_1 = \frac{2\pi d_1 N_1 cos(\theta_1)}{\lambda} \quad \text{--- (ก.16)}$$

อัตราส่วนความเข้มแสง (ความเข้มแสงที่สะท้อนออกจากแบบจำลองต่อความเข้มแสงที่ตกกระทบกับแบบจำลองสามารถคำนวณได้ดังสมการต่อไปนี้

$$\frac{I_{s,p}}{I_{0,p}} = \left|\frac{E_{s,p}}{E_{0,p}}\right|^2 = \left|r_{0123,p}\right|^2 \quad , \quad \frac{I_{s,s}}{I_{0,s}} = \left|\frac{E_{s,s}}{E_{0,s}}\right|^2 = \left|r_{0123,s}\right|^2 \quad \text{--- (ก.17)}$$

ก.3 การแทรกสอดของแสงในการวัด Flying height โดยใช้ดิสก์ที่มีชั้นของซิลิกอนและ DLC

จากวิธีการคำนวณที่ได้อธิบายไว้ยังหัวข้อที่ 1 และ 2 สามารถนำมาประยุกต์ใช้ในการคำนวณอัตราส่วนความเข้มแสงที่สะท้อนออกมาจากแบบจำลองการวัด Flying height ด้วยจานแก้วที่เคลือบด้วยซิลิกอนและ DLC ได้ โดยแบบจำลองการสะท้อนของแสงในการวัด Flying height แสดงไว้ดังรูปที่ ก.4 โดยที่แสงที่ตกกระทบทำมุมตั้งฉากกับผิวจานแก้ว $\left(\theta_0 = 0\right)$



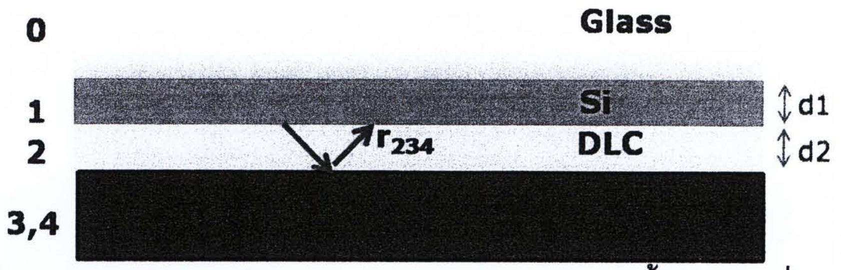
รูปที่ ก.4 แบบจำลองการสะท้อนของแสงในการวัด Flying height ด้วยจานแก้วที่เคลือบด้วยซิลิกอนและ DLC

จากรูปที่ ก.4 จะเริ่มจากการยุบรวมของชั้นของตัวกลางที่ 3 (อากาศ) และ 4 (AlTiC slider) ซึ่งสามารถการคำนวณแอมพลิจูดของสัมประสิทธิ์การสะท้อนของแสงของฟิล์มชั้นที่ 3 กับ 4 และการเปลี่ยนแปลงของเฟสของแสงเมื่อเดินทางผ่านชั้นตัวกลางที่ 3 ได้ดังนี้

$$r_{234} = \left[\frac{r_{23} + r_{34}e^{(2i\beta_3)}}{1 + r_{23}r_{34}e^{(2i\beta_3)}}\right] \qquad \text{--- (ก.18)}$$

$$\beta_3 = \frac{2\pi d_3 N_3}{\lambda} \qquad \text{--- (ก.19)}$$

โดยรูปที่ ก.5 แสดงถึงรูปที่ ก.4 หลังจากการยุบรวมของชั้นตัวกลางที 3 และ 4



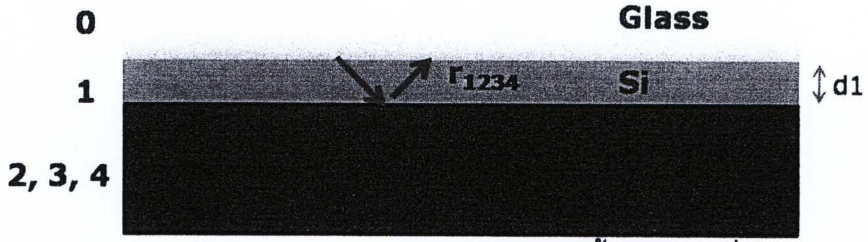
รูปที่ ก.5 แบบจำลองการวัด Flying height หลังจากยุบรวมชั้นตัวกลางที่ 3 และ 4

หลังจากนั้นทำการยุบรวมชั้นของตัวกลางที่ 2 (DLC) และ 3, 4 ซึ่งสามารถคำนวณแอมพลิจูดของสัมประสิทธิ์การสะท้อนของแสงของฟิล์มชั้นที่ 2 กับ 3, 4 และการเปลี่ยนแปลงของเฟสของแสงเมื่อเดินทางผ่านชั้นตัวกลางที่ 2 ได้ดังนี้

$$r_{1234} = \left[\frac{r_{12} + r_{234} e^{(2i\beta_2)}}{1 + r_{12} r_{234} e^{(2i\beta_2)}} \right] \quad \text{--- (ก.20)}$$

$$\beta_2 = \frac{2\pi d_2 N_2}{\lambda} \quad \text{--- (ก.21)}$$

โดยรูปที่ ก.6 แสดงถึงรูปที่ ก.4 หลังจากการยุบรวมของชั้นตัวกลางที 2 และ 3, 4



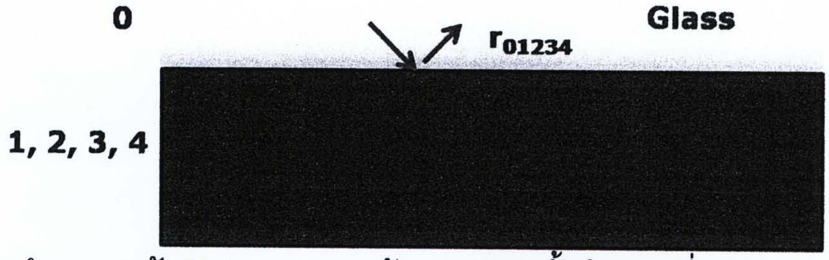
รูปที่ ก.6 แบบจำลองการวัด Flying height หลังจากยุบรวมชั้นตัวกลางที่ 2 และ 3, 4

หลังจากนั้นทำการยุบรวมชั้นของตัวกลางที่ 1 (ซิลิกอน) และ 2, 3, 4 ซึ่งสามารถคำนวณแอมพลิจูดของสัมประสิทธิ์การสะท้อนของแสงของฟิล์มชั้นที่ 1 กับ 2, 3, 4 และการเปลี่ยนแปลงของเฟสของแสงเมื่อเดินทางผ่านชั้นตัวกลางที่ 1 ได้ดังนี้

$$r_{01234} = \left[\frac{r_{01} + r_{1234} e^{(2i\beta_1)}}{1 + r_{01} r_{1234} e^{(2i\beta_1)}} \right] \quad \text{--- (ก.22)}$$

$$\beta_1 = \frac{2\pi d_1 N_1}{\lambda} \qquad \text{--- (ก.23)}$$

โดยรูปที่ ก.7 แสดงถึงรูปที่ ก.4 หลังจากการยุบรวมของชั้นตัวกลางที 1 และ 2, 3, 4 โดยที่ r_{01234} คือแอมพลิจูดของสัมประสิทธิ์การสะท้อนของแสงทั้งหมดที่สะท้อนออกมาจากแบบจำลองการวัด Flying height



รูปที่ ก.7 แบบจำลองการวัด Flying height หลังจากยุบรวมชั้นตัวกลางที่ 1 และ 2, 3, 4

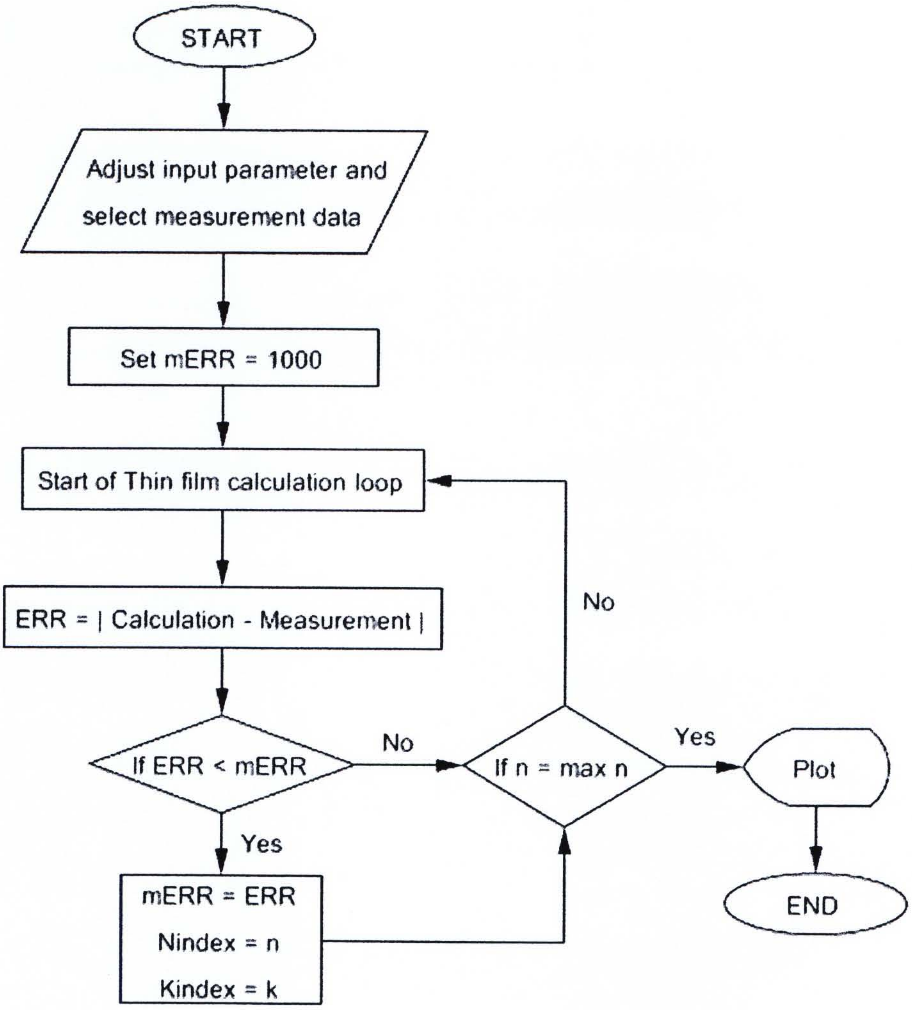
ซึ่งสามารถคำนวณอัตราส่วนความเข้มแสงทั้งหมดที่สะท้อนออกมาจากแบบจำลองได้ดังนี้

$$\frac{I_s}{I_0} = \left|\frac{E_s}{E_0}\right|^2 = \left|r_{01234}\right|^2 \qquad \text{--- (ก.24)}$$

ภาคผนวก ข

ชุดคำสั่งของโปรแกรมที่ประดิษฐ์ขึ้นโดยใช้ Matlab เพื่อใช้ในการคำนวณ

ข.1 โปรแกรมเพื่อ Fitting หาค่าดรรชนีหักเหของดิสก์จากค่าความเข้มแสงที่ได้จากการวัด



รูปที่ ข.1 Flowchart ของโปรแกรมที่ ข.1

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%% BEGIN PROGRAM %%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clc
clear all
%================ INPUT PARAMETERS ================

fh = [0e-9:1e-9:500e-9];              % Flying height (Air gap)
d = 15e-9;                            % DLC thickness
L = [650e-9];                         % Wave length Red 650, green
                                      % 550, blue 450
Mode = [2];                           % Measurement condition 1:glass
                                      % disk ,2:Si 1nm disk ,3:Si 5nm
MEA = 2;                % USE data from which measurement
FT_ON = 0;              % Fitting loop ON = 1, OFF = 0
FT_S = 1;               % Fit start and stop
FT_ST = 4;
PLD = 200;              % PLOT display to this FH
SHF = 0;                % Amount of FH shift of each point, minimum
                        % value can't lower than -19
NS = 1.2;               % N initial
NF = 5;                 % N final
KS = 0;                 % K initial
KF = 0.02;              % K final
ST = 0.01;              % Step to vary nc and kc for iteration loop
%==================================================================
mERR = 1000;
Iter = 0;
if L == 450e-9
            Ng = 1.54+0.02i;                % Glass
            Ns = 3.926+1.404i;              % Si amorphous
            Nd = 2.169+0.2087i;             % DLC
            Na = 1;                         % Air
            Nh = 2.39+0.432i;               % AlTiC
            if Mode == 1
                PT2(1) = 1028.6;
                PT2(2) = 1516;
                PT2(3) = 1942.85;
                PT2(4) = 2246.965;
             %===========================
                PT2_min(1) = 742;
                PT2_min(2) = 721;
                PT2_min(3) = 733;
                PT2_min(4) = 718;
             %===========================
                PT2_max(1) = 2406;
                PT2_max(2) = 2313;
                PT2_max(3) = 2414;
                PT2_max(4) = 2403;
            elseif Mode == 2
                PT2(1) = 548.465;
                PT2(2) = 873.253;
                PT2(3) = 1300.223;
                PT2(4) = 1708.532;
             %===========================
                PT2_min(1) = 582;
                PT2_min(2) = 576;
                PT2_min(3) = 555;
                PT2_min(4) = 516;
             %===========================
                PT2_max(1) = 2268;
                PT2_max(2) = 2188;
                PT2_max(3) = 2265;
```

```
            PT2_max(4) = 2264;
        elseif Mode == 3
            PT2(1) = 318.363;
            PT2(2) = 584.634;
            PT2(3) = 875.948;
            PT2(4) = 1143.104;
         %==========================
            PT2_min(1) = 336;
            PT2_min(2) = 341;
            PT2_min(3) = 317;
            PT2_min(4) = 309;
         %==========================
            PT2_max(1) = 1595;
            PT2_max(2) = 1567;
            PT2_max(3) = 1604;
            PT2_max(4) = 1595;
        end
elseif L == 550e-9
        Ng = 1.51+0.01i;                    % Glass
        Ns = 3.789+0.951i;                  % Si amorphous
        Nd = 2.1699+0.1416i;                % DLC
        Na = 1;                             % Air
        Nh = 2.354+0.363i;                  % AlTiC
        if Mode == 1
            PT2(1) = 926.152;
            PT2(2) = 1268;
            PT2(3) = 1612.227;
            PT2(4) = 1910.342;
        %==========================
            PT2_min(1) = 736;
            PT2_min(2) = 717;
            PT2_min(3) = 724;
            PT2_min(4) = 717;
        %==========================
            PT2_max(1) = 2250;
            PT2_max(2) = 2174;
            PT2_max(3) = 2261;
            PT2_max(4) = 2257;
        elseif Mode == 2
            PT2(1) = 603.834;
            PT2(2) = 834.358;
            PT2(3) = 1171.059;
            PT2(4) = 1533.226;
        %==========================
            PT2_min(1) = 635;
            PT2_min(2) = 616;
            PT2_min(3) = 615;
            PT2_min(4) = 604;
        %==========================
            PT2_max(1) = 2255;
            PT2_max(2) = 2186;
            PT2_max(3) = 2259;
            PT2_max(4) = 2255;
        elseif Mode == 3
            PT2(1) = 237.783;
            PT2(2) = 446.363;
            PT2(3) = 726.075;
            PT2(4) = 1007.907;
        %==========================
            PT2_min(1) = 279;
            PT2_min(2) = 278;
```

```
            PT2_min(3) = 256;
            PT2_min(4) = 250;
        %------------------------------------
            PT2_max(1) = 1578;
            PT2_max(2) = 1569;
            PT2_max(3) = 1598;
            PT2_max(4) = 1596;
        end
elseif L == 650e-9
        Ng = 1.52;                          % Glass
        Ns = 3.711+0.7261i;                 % Si amorphous
        Nd = 2.1631+0.0985i;                % DLC
        Na = 1;                             % Air
        Nh = 2.289+0.344i;                  % AlTiC
        if Mode == 1
            PT2(1) = 907.842;
            PT2(2) = 1250.883;
            PT2(3) = 1625.133;
            PT2(4) = 1984.017;
        %------------------------------------
            PT2_min(1) = 727;
            PT2_min(2) = 689;
            PT2_min(3) = 710;
            PT2_min(4) = 699;
        %------------------------------------
            PT2_max(1) = 2639;
            PT2_max(2) = 2542;
            PT2_max(3) = 2643;
            PT2_max(4) = 2640;
        elseif Mode == 2
            PT2(1) = 598.335;
            PT2(2) = 830.244;
            PT2(3) = 1181.986;
            PT2(4) = 1594.638;
        %------------------------------------
            PT2_min(1) = 628;
            PT2_min(2) = 599;
            PT2_min(3) = 610;
            PT2_min(4) = 592;
        %------------------------------------
            PT2_max(1) = 2725;
            PT2_max(2) = 2637;
            PT2_max(3) = 2728;
            PT2_max(4) = 2735;
        elseif Mode == 3
            PT2(1) = 214.815;
            PT2(2) = 391.986;
            PT2(3) = 687.532;
            PT2(4) = 1026.384;
        %------------------------------------
            PT2_min(1) = 250;
            PT2_min(2) = 246;
            PT2_min(3) = 246;
            PT2_min(4) = 234;
        %------------------------------------
            PT2_max(1) = 1971;
            PT2_max(2) = 1952;
            PT2_max(3) = 1981;
            PT2_max(4) = 1980;
        end
end
```

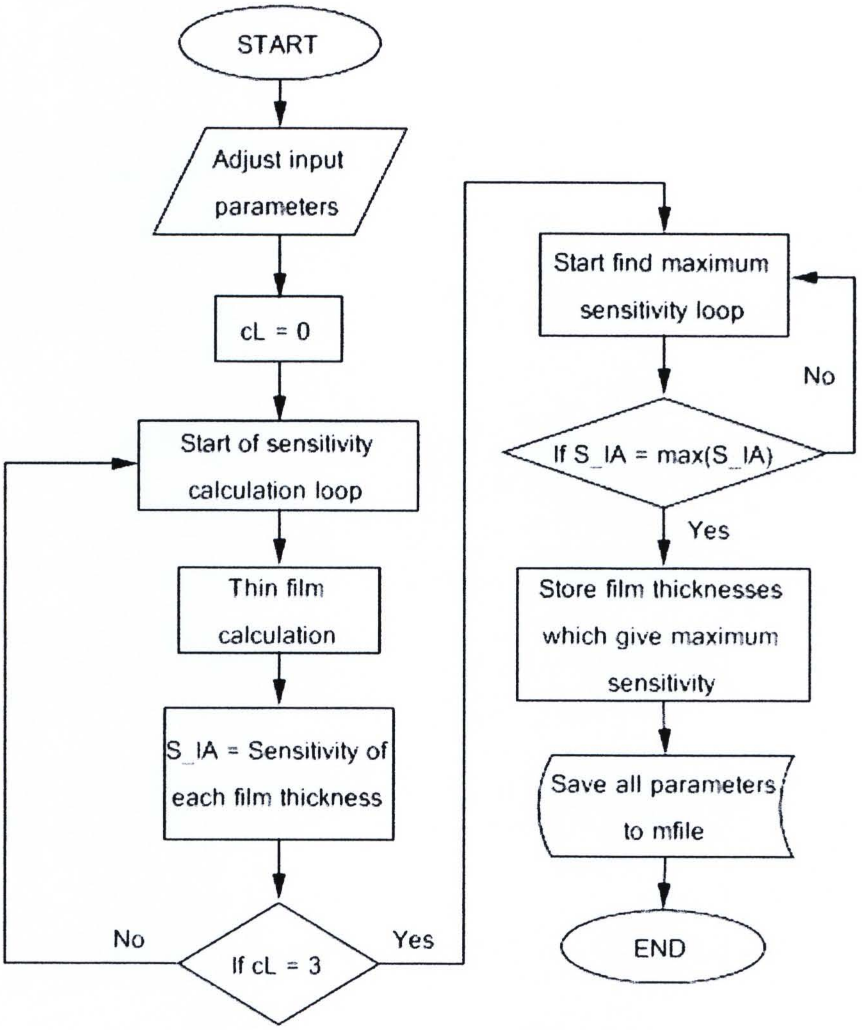
```
%---- DEFINE FILM THICKNESS AND FH FROM MEASUREMENT
    if Mode == 1
        fhm2(1) = 19.79;          %  FH from measurement of each point
        fhm2(2) = 43.6;
        fhm2(3) = 61.99;
        fhm2(4) = 81.98;
        TXT = 'Glass';
    elseif Mode == 2
        T = 1e-9;                 %  Si thickness
        fhm2(1) = 19.79;
        fhm2(2) = 43.6;
        fhm2(3) = 61.99;
        fhm2(4) = 81.98;
        TXT = 'Si 1nm';
    elseif Mode == 3
        T = 5e-9;                 %  Si thickness
        fhm2(1) = 19.79;
        fhm2(2) = 43.6;
        fhm2(3) = 61.99;
        fhm2(4) = 81.98;
        TXT = 'Si 5nm';
    end
for Nc = NS:ST:NF
    for Kc = KS:ST:KF
        Iter = Iter+1;
        nc = [complex(Nc,Kc),         % refracrive index of composite
                                      % which iterated(Nc,Kc)
                1,                    % refractive index of air
                Nh];                  % refractive index of AlTiC
%==============================================================
%========        ASSIGN Rij,Tij           ===============
%==============================================================
        for u = 1:length(nc)
            for v = 1:length(nc)
                rco(u,v) = (nc(u)-nc(v))/(nc(u)+nc(v));
                tco(u,v) = 2*nc(u)/(nc(u)+nc(v));
            end
        end
%==============================================================
%======      DEFINE 1st composite layer        ========
%==============================================================
%----COMP------1
%----Air-------2
%----AlTiC-----3
        Rdm = rco(1,2);  % Beam which reflect from middle layer
        Rdb = rco(2,3);  % Beam which reflect from bottom layer
        for u = 1:length(fh)
      Bc(u) = (2*pi*fh(u)*nc(2))/L;
   RC(u,1) = (Rdm+Rdb*(exp(2*i*Bc(u))))/(1+Rdm*Rdb*(exp(2*i*Bc(u))));
            AmpC(u,1) = abs(RC(u,1))^2;
            PhsC(u,1) = angle(RC(u,1));
        end
%==============================================================
%======      NORMALIZED INTENSITY TO 0-2       =======
%==============================================================
        AmpC_N = AmpC-min(AmpC);
        m_CN = 2/max(AmpC_N);
        AmpC_N2 = AmpC_N.*m_CN;

%==============================================================
%======     MEASUREMENT LOOP   =======================
```

```
%=========================================================
% Use intensity from measurement from each case to re-plot FH
        if MEA == 1
            PT = PT1;
            PT_min = PT1_min;
            PT_max = PT1_max;
            fhm = fhm1+SHF;
            MTXT = '1st';
        elseif MEA == 2
            PT = PT2;
            PT_min = PT2_min;
            PT_max = PT2_max;
            fhm = fhm2+SHF;
            MTXT = '2nd';
        elseif MEA == 3
            PT = PT3;
            PT_min = PT3_min;
            PT_max = PT3_max;
            fhm = fhm3+SHF;
            MTXT = '3rd';
        elseif MEA == 0
            ac1 = 0;
            %==== Merge data from 1&2 measurement ===
            for a1 = 1:length(fhm1)
                fhmd(a1,1) = fhm1(a1);
                PTd(a1,1) = PT1(a1);
                PTd_min(a1,1) = PT1_min(a1);
                PTd_max(a1,1) = PT1_max(a1);
            end
            for a2 = length(fhm1)+1:length(fhm1)+length(fhm2)
                ac1 = ac1+1;
                fhmd(a2,1) = fhm2(ac1);
                PTd(a2,1) = PT2(ac1);
                PTd_min(a2,1) = PT2_min(ac1);
                PTd_max(a2,1) = PT2_max(ac1);
            end
            %============================================
            %=== Sort intensity data by assending fh ===
            fhmdS = sort(fhmd);
            for as = 1:length(fhmd)
                for as2 = 1:length(fhmd)
                    if fhmdS(as) == fhmd(as2)
                        A_index(as,1) = as2;
                    end
                end
            end
            %=== Define all necessary input parameters ==
            for Is = 1:length(fhmd)
                PT(Is,1) = PTd(A_index(Is));
                PT_min(Is,1) = PTd_min(A_index(Is));
                PT_max(Is,1) = PTd_max(A_index(Is));
            end
            fhm = fhmdS+SHF;
            MTXT = 'ALL';
        end
        for m = 1:length(fhm)
            IP(m) = ((PT(m)-PT_min(m))/(PT_max(m)-PT_min(m)))*2;
            if IP(m) < 0
                IP(m) = 0;
            end
        end
```

```
        if FT_ON == 0
            break, end
%=====================================================================
%=======     FITTING LOOP    ========================
%=====================================================================
% Fit N&K which its intensity give nearest FH to measurement data
        CT = 0;
        Cf = 0;
        for u = FT_S:FT_ST
            CT = CT+1;
            mI = 200;
            for v = 1:round(max(fhm))+1+5
                Cf = Cf+1;
                fERR(Cf,1) = abs(AmpC_N2(v)-IP(u));
                if fERR(Cf,1)<mI
                    mI = fERR(Cf,1);
                    fhC = v-1;
                end
            end
            FHC(CT) = fhC;    % Find the FH of each intensity which
nearest to measured intensity
        end
        Sfhm = size(fhm(FT_S:FT_ST));
        SFHC = size(FHC);
        if Sfhm(1,1) ~= SFHC(1,1)
            FHC = FHC';
        end
        ERR(Iter,1) = sum((fhm(FT_S:FT_ST)-FHC).^2);
        if  ERR(Iter)< mERR
            mERR = ERR(Iter);
            Nindex = Nc;
            Kindex = Kc;
            FHC2 = FHC;
        end
    end
end
if FT_ON == 1
%==========================================================================
%========================     FOR PLOT    ==============================
%==========================================================================
np = [complex(Nindex,Kindex),       % refracrive index of composite
                                    % which iterated(Nc,Kc)
                1,                  % refractive index of air
                Nh];                % refractive index of AlTiC
%=====================================================================
%=======        ASSIGN Rij,Tij          ==============
%=====================================================================
        for u = 1:length(np)
            for v = 1:length(np)
                rcp(u,v) = (np(u)-np(v))/(np(u)+np(v));
                tcp(u,v) = 2*np(u)/(np(u)+np(v));
            end
        end
%=====================================================================
%======      DEFINE 1st composite layer        ========
%=====================================================================
%----COMP------1
%----Air-------2
%----AlTiC-----3
        Rdm = rcp(1,2);  % Beam which reflect from middle layer
        Rdb = rcp(2,3);  % Beam which reflect from bottom layer
```

```
        for u = 1:length(fh)
    Bp(u) = (2*pi*fh(u)*np(2))/L;
    Rp(u,1) = (Rdm+Rdb*(exp(2*i*Bp(u))))/(1+Rdm*Rdb*(exp(2*i*Bp(u))));
    AmpP(u,1) = abs(Rp(u,1))^2;
    PhsP(u,1) = angle(Rp(u,1));
        end
%========================================================================
%=======      NORMALIZED INTENSITY TO 0-2       ========
%========================================================================
        AmpP_N = AmpP-min(AmpP);
        m_PN = 2/max(AmpP_N);
        AmpP_N2 = AmpP_N.*m_PN;
%========================================================================
    if L == 450e-9
        Co = 'b';
        Co2 = 'b*';
    elseif L == 550e-9
        Co = 'g';
        Co2 = 'g*';
    elseif L == 650e-9
        Co = 'r';
        Co2 = 'r*';
    end
plot(fh(1:PLD).*10^9,AmpP_N2(1:PLD),Co,fhm,IP,Co2)
legend(['n = ',num2str(Nindex),',k = ',num2str(Kindex)])
title(['Fitting of ',TXT,' disk with ',MTXT,' measurement data with
point ',num2str(FT_S),' to ',num2str(FT_ST),])
ylabel('Intensity ratio')
xlabel('FH(nm)')
grid on
grid minor
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% END PROGRAM %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

ข.2 โปรแกรมเพื่อ Optimize sensitivity โดยการเปลี่ยนแปลงความหนาของซิลิกอนและ DLC



รูปที่ ข.2 Flowchart ของโปรแกรมที่ ข.2

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%% BEGIN PROGRAM %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clc
clear all
%=================================================================
%================= INPUT PARAMETERS ================
%=================================================================
fh = [0e-9:1e-9:400e-9];             % Flying height (Air gap)
T1 = [0e-9:0.5e-9:2e-9];             % 1st SiO2 thickness
d1 = [45e-9:1e-9:65e-9];             % 1st DLC thickness
T2 = [2e-9:0.5e-9:4e-9];             % SiO2 thickness
d2 = [15e-9:1e-9:35e-9];             % 2nd DLC thickness
WL = [450e-9,550e-9,650e-9];         % Wave length 650/550/450e-9
                                     % only are allowed
Add_layer = 'Si';
%=================================================================
%==========          LAYER          ==============
%=================================================================
cL = 0;
MX = 0;
for iL = 1:length(WL)
    L = WL(iL);
    cL = cL+1;     % Define loop number
    cs = 0;
    if L == 450e-9
            Ng = 1.54+0.02i;                % Glass
            Ns = 4.419+1.328i;              % Si amorphous
            Nso = 1.465;                    % SiO2
            Nal = 1.78;                     % Al2O3
            Nd = 2.169+0.2087i;             % DLC
            Na = 1;                         % Air
            Nh = 2.39+0.432i;               % AlTiC
    elseif L == 550e-9
            Ng = 1.51+0.01i;                % Glass
            Ns = 4.232+0.634i;              % Si amorphous
            Nso = 1.459;                    % SiO2
            Nal = 1.77;                     % Al2O3
            Nd = 2.1699+0.1416i;            % DLC
            Na = 1;                         % Air
            Nh = 2.354+0.363i;              % AlTiC
    elseif L == 650e-9
            Ng = 1.52;                      % Glass
            Ns = 4.014+0.309i;              % Si amorphous
            Nso = 1.456;                    % SiO2
            Nal = 1.765;                    % Al2O3
            Nd = 2.1631+0.0985i;            % DLC
            Na = 1;                         % Air
            Nh = 2.289+0.344i;              % AlTiC
    end
        %-----GLASS-----1
        %-----SiO2------2
        %-----DLC1------3
        %-----SiO2------4
        %-----DLC2------5
        %-----Air-------6
        %-----AlTiC-----7
        if Add_layer == 'S'
        n = [Ng,        % Glass
            Nso,        % SiO2 (T1)
            Nd,         % DLC 1
            Nso,        % SiO2 (T2)
            Nd,         % DLC 2
```

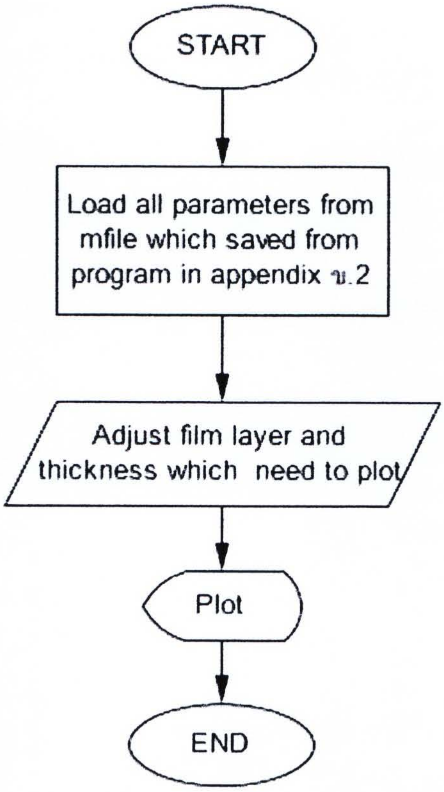
```
                Na,         % Air
                Nh];        % AlTiC
            elseif Add_layer == 'A'
             n = [Ng,       % Glass
                Nal,        % Al2O3_1
                Nd,         % DLC 1
                Nal,        % Al2O3_2
                Nd,         % DLC 2
                Na,         % Air
                Nh];        % AlTiC
            elseif Add_layer == 'Si'
             n = [Ng,       % Glass
                Ns,         % Si1
                Nd,         % DLC 1
                Ns,         % Si2
                Nd,         % DLC 2
                Na,         % Air
                Nh];        % AlTiC
            end
%==================================================================
%=======       ASSIGN Rij,Tij          ==========================
%==================================================================
        for u = 1:length(n)
            for v = 1:length(n)
                r(u,v) = (n(u)-n(v))/(n(u)+n(v));
                t(u,v) = 2*n(u)/(n(u)+n(v));
            end
        end
        c= 0;
        cd = 0;
        for z = 1:length(T1)
            for x = 1:length(d1)
                for w = 1:length(T2)
                    for v = 1:length(d2)
                        for u = 1:length(fh)
%==================================================================
%======       DEFINE 1st composite layer        =========
%==================================================================
%----DLC2------5
%----Air-------6
%----AlTiC-----7
        Rdm = r(5,6);  % Beam which reflect from middle layer
        Rdb = r(6,7);  % Beam which reflect from bottom layer
        B(u) = (2*pi*fh(u)*n(6))/L;    % BETA, Below r of composite 1
        rc1(u,1) = (Rdm+Rdb*(exp(2*i*B(u))))/(1+Rdm*Rdb*(exp(2*i*B(u))));
%==================================================================
%======       DEFINE 2nd composite layer        =========
%==================================================================
%-----SiO2------4
%----DLC2------5
%----COMP1-----rc1
A(v,1) = (2*pi*d2(v)*n(5))/L;  % ALPHA, Below r of material
Rdm = r(4,5);      % Beam which reflect from middle layer
Rdb = rc1(u,1);    % Beam which reflect from bottom layer
rc2(v,u) = (Rdm+Rdb*(exp(2*i*A(v,1))))/(1+Rdm*Rdb*(exp(2*i*A(v,1))));
%==================================================================
%======       DEFINE 3rd composite layer        =========
%==================================================================
%-----DLC1-----3
%-----SiO2-----4
%----COMP2-----rc2
```

```
G(w,1) = (2*pi*T2(w)*n(4))/L;  % ALPHA, Below r of material
Rdm = r(3,4);      % Beam which reflect from middle layer
Rdb = rc2(v,u);    % Beam which reflect from bottom layer
rc3(w,v,u)=(Rdm+Rdb*(exp(2*i*G(w,1))))/(1+Rdm*Rdb*(exp(2*i*G(w,1))));
%=================================================================
%=======      DEFINE 4th composite layer      ========
%=================================================================
%------Glass----2
%------DLC1-----3
%----COMP3-----rc3
O(x,1) = (2*pi*d1(x)*n(3))/L;  % ALPHA, Below r of material
Rdm = r(2,3);       % Beam which reflect from middle layer
Rdb = rc3(w,v,u);   % Beam which reflect from bottom layer
rc4(x,w,v,u)=
(Rdm+Rdb*(exp(2*i*O(x,1))))/(1+Rdm*Rdb*(exp(2*i*O(x,1))));
%=================================================================
%=======      DEFINE 5th composite layer      ========
%=================================================================
%------Glass----1
%------SiO2-----2
%----COMP4-----rc4
AL = (2*pi*T1(z)*n(2))/L;  % ALPHA, Below r of material
Rdm = r(1,2);          % Beam which reflect from middle layer
Rdb = rc4(x,w,v,u);    % Beam which reflect from bottom layer
rc5(z,x,w,v,u) = (Rdm+Rdb*(exp(2*i*AL)))/(1+Rdm*Rdb*(exp(2*i*AL)));
                        Amp(z,x,w,v,u) = abs(rc5(z,x,w,v,u))^2;
                        Phs(z,x,w,v,u) = angle(rc5(z,x,w,v,u));
                    if u == length(fh)
                AmpN(z,x,w,v,:) = Amp(z,x,w,v,:)-min(Amp(z,x,w,v,:));
                mN = 2/max(AmpN(z,x,w,v,:));
                AmpN2(z,x,w,v,:) = AmpN(z,x,w,v,:).*mN;
                        %====================================
                        %========== SENSITIVITY ==========
                        %====================================
                cs = cs+1;
                S_arr1 = [1,10,20,30,40,50];
                S_arr2 = [2,12,22,32,42,52];
                DS_I = AmpN2(z,x,w,v,S_arr2)-AmpN2(z,x,w,v,S_arr1);
                % Dummy to store first rc3, cal from 1st value of FH
                        S_I(cs,cL) = sum(DS_I);
                        if cL == 1
                            Mt_index(cs,1) = z;  % 1st SiO2 layer
                            Mt_index(cs,2) = x;  % 1st DLC layer
                            Mt_index(cs,3) = w;  % 2nd SiO2 layer
                            Mt_index(cs,4) = v;  % 2nd DLC layer
                        end
                        end
                    end
                end
            end
        end
    end
%==========================================================================
%=========  STORE SENSITIVITY OF EACH WAVELENGTH    ==========
%==========================================================================
    if cL == 1
        AmpB = AmpN2;
        S_I1 = S_I(:,cL);
    elseif cL == 2
        AmpG = AmpN2;
        S_I2 = S_I(:,cL);
```

```
    elseif cL == 3
        AmpR = AmpN2;
        S_I3 = S_I(:,cL);
    end
end
%===============================================================================
%=========        END CALCULATION LOOP         =======================
%===============================================================================
%====== POST PROCESSING LOOP   ========
S_IA = S_I1+S_I2+S_I3;
for xs = 1:cs
    if S_IA(xs) == max(S_IA)
        MX = MX+1;
        M_index(MX) = xs;
    end
end
for i = 1:length(M_index)
    SiO1(i) = Mt_index(M_index(i),1);
    DLC1(i) = Mt_index(M_index(i),2);
    SiO2(i) = Mt_index(M_index(i),3);
    DLC2(i) = Mt_index(M_index(i),4);

    DLC1_T(i) = d1(DLC1(i))*10^9;
    SiO1_T(i) = T1(SiO1(i))*10^9;
    DLC2_T(i) = d2(DLC2(i))*10^9;
    SiO2_T(i) = T2(SiO2(i))*10^9;
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%% END PROGRAM %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

ข.3 โปรแกรมเพื่อวิเคราะห์ Sensitivity ที่ได้จากโปรแกรม ข.2 (ต้องทำการ Run โปรแกรม ข.2 ก่อน)

สามารถ Run โปรแกรม ข.2 และบันทึกผลของโปรแกรมไว้ก่อนและนำผลมาเรียกใช้กับโปรแกรม ข.3 เพื่อวิเคราะห์ Sensitivity ในการวัด Flying height ในช่วงความหนาที่ต้องการ



รูปที่ ข.3 Flowchart ของโปรแกรมที่ ข.3

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%% BEGIN PROGRAM %%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% NEED TO RUN TEST_SENSE_2.m first
clear S_IAT i j F1 F2 X Y TF TF_L

FX = '24';                  % Fix film thickness for plot, first digit
                            % is 1st fixed layer where
                            % the second digit define the 2nd fixed
                            % layer
T_FX = 55;                  % Thickness of layer FX whick fixed,
                            % this value must not exceed range of
                            % thickness of array above


T_FX2 = 25;
PLC = 2;
PLD = 400;
DLC1_T;                     % Real thickness DLC, SiO2 and DLC which
                            % has highest sensitivity

SiO2_T;
DLC2_T;
Plus1 = 0;
Plus2 = 0;
```

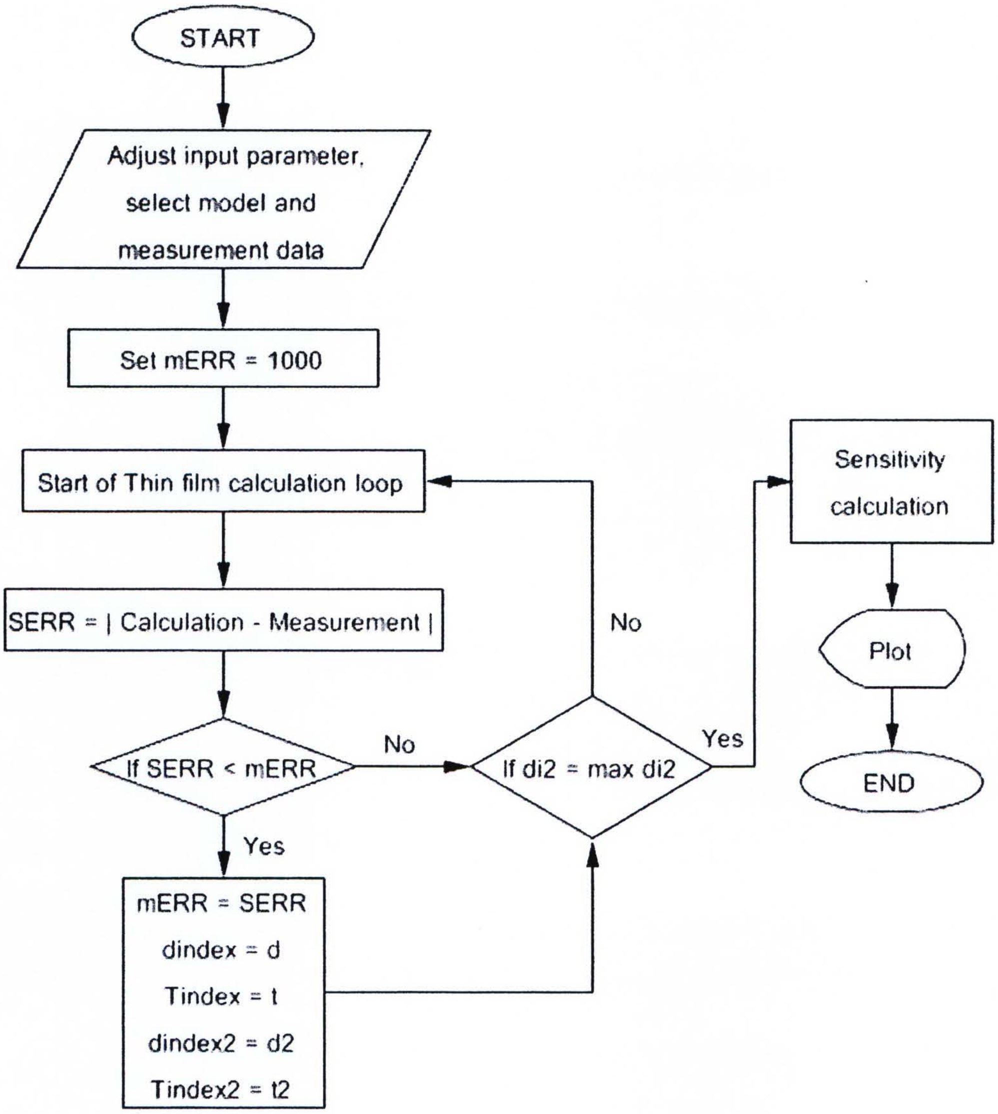
```
for u = 1:length(fh)
    AmpBP(u,1) = AmpB(SiO1,DLC1,SiO2,DLC2,u);
    AmpGP(u,1) = AmpG(SiO1,DLC1,SiO2,DLC2,u);
    AmpRP(u,1) = AmpR(SiO1,DLC1,SiO2,DLC2,u);
end
%----Glass-----1
%----Air-------2
%----AlTiC-----3
for iL = 1:length(WL)
        L = WL(iL);
        cL = cL+1;                              % Define loop number
         if L == 450e-9
            Ng = 1.54+0.02i;                    % Glass
            Ns = 4.419+1.328i;                  % Si amorphous
            Nso = 1.465;                        % SiO2
            Nal = 1.78;                         % Al2O3
            Nd = 2.169+0.2087i;                 % DLC
            Na = 1;                             % Air
            Nh = 2.39+0.432i;                   % AlTiC
    elseif L == 550e-9
            Ng = 1.51+0.01i;                    % Glass
            Ns = 4.232+0.634i;                  % Si amorphous
            Nso = 1.459;                        % SiO2
            Nal = 1.77;                         % Al2O3
            Nd = 2.1699+0.1416i;                % DLC
            Na = 1;                             % Air
            Nh = 2.354+0.363i;                  % AlTiC
    elseif L == 650e-9
            Ng = 1.52;                          % Glass
            Ns = 4.014+0.309i;                  % Si amorphous
            Nso = 1.456;                        % SiO2
            Nal = 1.765;                        % Al2O3
            Nd = 2.1631+0.0985i;                % DLC
            Na = 1;                             % Air
            Nh = 2.289+0.344i;                  % AlTiC
    end
      ng = [Ng,     % Glass
            Na,     % Air
            Nh];    % AlTiC
    for u = 1:length(ng)
        for v = 1:length(ng)
            rg(u,v) = (ng(u)-ng(v))/(ng(u)+ng(v));
            tg(u,v) = 2*ng(u)/(ng(u)+ng(v));
        end
    end
    for u = 1:length(fh)
   Rdm = rg(1,2);  % Beam which reflect from middle layer
   Rdb = rg(2,3);  % Beam which reflect from bottom layer
   Bg(u) = (2*pi*fh(u)*ng(2))/L;    % BETA, Below r of composite model
   Rg(u,1) = (Rdm+Rdb*(exp(2*i*Bg(u))))/(1+Rdm*Rdb*(exp(2*i*Bg(u))));
   % Light reflect from composite model
   Ampg(u,1) = abs(Rg(u,1))^2;
   Phsg(u,1) = angle(Rg(u,1));
    end
    AmpgN = Ampg-min(Ampg);
    mgN = 2/max(AmpgN);
    AmpgN2 = AmpgN.*mgN;
    if L == 450e-9
        AMPG_NB = AmpgN2;
    elseif L == 550e-9
        AMPG_NG = AmpgN2;
```

```
    elseif L == 650e-9
        AMPG_NR = AmpgN2;
    end
end
if PLC == 2
    switch FX
            case '24'
                FX1 = 2;
                FX2 = 4;
                F1 = length(T1);
                F2 = length(T2);
                X = T1.*10^9;
                Y = T2.*10^9;
                TF1 = d1.*10^9;
                TF2 = d2.*10^9;
                XTXT = [Add_layer,' 1st layer'];
                YTXT = [Add_layer,' 2nd layer'];
                TTXT = ['Sensitivity: fixed DLC 1st at
',num2str(T_FX),' nm and 2nd layer at ',num2str(T_FX2),' nm'];
            case '13'
                FX1 = 1;
                FX2 = 3;
                F1 = length(d1);
                F2 = length(d2);
                X = d1.*10^9;
                Y = d2.*10^9;
                TF1 = T1.*10^9;
                TF2 = T2.*10^9;
                XTXT = 'DLC 1st layer';
                YTXT = 'DLC 2nd layer';
                TTXT = ['Sensitivity: fixed ',Add_layer,' 1st at
',num2str(T_FX),' nm and 2nd layer at ',num2str(T_FX2),' nm'];
            case '34'
                FX1 = 3;
                FX2 = 4;
                F1 = length(T1);
                F2 = length(d1);
                X = T1.*10^9;
                Y = d1.*10^9;
                TF1 = T2.*10^9;
                TF2 = d2.*10^9;
                XTXT = [Add_layer,' 1st layer';
                YTXT = 'DLC 1st layer';
                TTXT = ['Sensitivity: fixed ',Add_layer,' 1st at
',num2str(T_FX),' nm and 1st DLC layer at ',num2str(T_FX2),' nm'];
            end
   sT_FX = num2str(T_FX);
   fsT_FX = findstr(sT_FX,'.');
   sT_FX2 = num2str(T_FX2);
   fsT_FX2 = findstr(sT_FX2,'.');
   if fsT_FX > 0
            T_FX = T_FX*100;
            TF1 = TF1.*100;
            Plus1 = 1;
   end
   if fsT_FX2 > 0
            T_FX2 = T_FX2*100;
            TF2 = TF2.*100;
            Plus2 = 1;
   end
    for i = 1:length(TF1)
```

```
        if round(T_FX) == round(TF1(i))
            TF_L = i;
        end
    end
    for i = 1:length(TF2)
        if round(T_FX2) == round(TF2(i))
            TF_L2 = i;
        end
    end
    if Plus1 == 1;
        T_FX = T_FX/100;
        TF1 = TF1./100;
    end
    if Plus2 == 1;
        T_FX2 = T_FX2/100;
        TF2 = TF2./100;
    end
    ck = 0;
    for i = 1:cs
        if Mt_index(i,FX1) == TF_L && Mt_index(i,FX2) == TF_L2
            ck = ck+1;
            T_index(ck,1) = i;
        end
    end
    ck2 = 0;
    for i = 1:F1
        for j = 1:F2
            ck2 = ck2+1;
            S_IAT(i,j) = S_IA(T_index(ck2));
        end
    end
    S_IAP = ((S_IA-0.6013)./0.6013).*100;
    S_IAT = ((S_IAT-0.6013)./0.6013).*100;

    for i = 1:F1
        for j = 1:F2
            if S_IAT(i,j)< 0
                S_IAT(i,j) = 0;
            end
        end
    end

    for i = 1:F1
        for j = 1:F2
            if S_IAT(i,j) == max(max(S_IAT))
                XM = X(i);
                YM = Y(j);
            end
        end
    end
    contourf(X,Y,S_IAT',20)
    colorbar
    grid minor
    title(TTXT)
    xlabel(XTXT)
    ylabel(YTXT)
    hold on
    plot(XM,YM,'-
mo','LineWidth',2,'MarkerEdgeColor','w','MarkerFaceColor','b','marker
size',6);
```

```
    text(XM,YM-((Y(2)-Y(1))),['\fontsize{13}\bf\color{white} S =
',num2str(max(max(S_IAT))),' at (',num2str(XM),',',num2str(YM),')'])
    hold on
end


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% END PROGRAM %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

ข.4 โปรแกรมเพื่อ Fitting ความเข้มแสงที่ได้จากการวัดเพื่อหาความหนาของฟิล์ม และคำนวณ Sensitivity ที่ได้จากความหนานั้น



รูปที่ ข.4 Flowchart ของโปรแกรมที่ ข.4

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%% BEGIN PROGRAM %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clc
clear all
%================ INPUT PARAMETERS ================
fh = [0e-9:1e-9:500e-9];             % Flying height (Air gap)
WL = [450e-9, 550e-9, 650e-9];       % Wave length Red 650, green 550,
                                     % blue 450
Mode = 1;                            % Measurement condition 1: AVG data
                                     % of Si1/DLC77 (3Layers)
                                     % 2: AVG data of 5Layers disk

FT_ON = 1;                 % Fitting loop ON = 1, OFF = 0
FT_S = 1;                  % Fit start and stop
FT_ST = 4;

PLD = 100;                 % PLOT display to this FH
SHF = 0;                   % Amount of FH shift of each point, minimum
                           % value can't lower than -19

DS1 = [60,80];             % Thickness range of DLC1
DS2 = [21,29];             % Thickness range of DLC2
SS1 = [0.5,1.2];           % Thickness range of Si1
SS2 = [2.5,3.5];           % Thickness range of Si2

SD = 1;               % Step to vary DLC thickness for iteration loop
ST = 0.01;            % Step to vary Si thickness for iteration loop
SC = 20;              % Sensitivity cal Only 20 and 50 can be input
%==========================================================
%==========================================================
%==========       DEFINE RELATION          ===============
%==========================================================
if Mode == 1
    MEA = 1;
    DS2 = [1,1];
    SS2 = [1,1];
    fhm1(1) = 18.94;
    fhm1(2) = 44.6;
    fhm1(3) = 63;
    fhm1(4) = 83.2;
elseif Mode == 2
    MEA = 2;
    fhm2(1) = 16.09;
    fhm2(2) = 42.2;
    fhm2(3) = 60.6;
    fhm2(4) = 80.54;
end
%==========================================================
%==========         CALCULATION           ================
%==========================================================
mERR = 1000;
Iter = 0;
for di2 = DS2(1):SD:DS2(2)
    for Ti2 = SS2(1):ST:SS2(2)
        for di = DS1(1):SD:DS1(2)
            for Ti = SS1(1):ST:SS1(2)
            d = di*1e-9;
            T = Ti*1e-9;
            if Mode == 1
                d2 = 0;
```

```
            T2 = 0;
        else
            d2 = di2*1e-9;
            T2 = Ti2*1e-9;
        end
        Iter = Iter+1;
    for LC = 1:length(WL)
        L = WL(LC);
    if L == 450e-9
        Ng = 1.54+0.02i;                        % Glass
        Ns = 4.419+1.328i;                      % Si amorphous
        Nd = 2.169+0.2087i;                     % DLC
        Na = 1;                                 % Air
        Nh = 2.39+0.432i;                       % AlTiC
        if Mode == 1
            PT1(1) = 524.182;
            PT1(2) = 763.879;
            PT1(3) = 881.348;
            PT1(4) = 949.955;
          %==========================
            PT1_min(1) = 223;
            PT1_min(2) = 226.4;
            PT1_min(3) = 213;
            PT1_min(4) = 212.4;
          %==========================
            PT1_max(1) = 961.6;
            PT1_max(2) = 949;
            PT1_max(3) = 963.8;
            PT1_max(4) = 978.6;
        elseif Mode == 2
            PT2(1) = 719.313;
            PT2(2) = 978.59;
            PT2(3) = 1102.848;
            PT2(4) = 1140.988;
          %==========================
            PT2_min(1) = 298.6;
            PT2_min(2) = 302.4;
            PT2_min(3) = 289.8;
            PT2_min(4) = 287.4;
          %==========================
            PT2_max(1) = 1152.8;
            PT2_max(2) = 1131.4;
            PT2_max(3) = 1174.8;
            PT2_max(4) = 1160.6;
        end
    elseif L == 550e-9
        Ng = 1.51+0.01i;                        % Glass
        Ns = 4.232+0.634i;                      % Si amorphous
        Nd = 2.1699+0.1416i;                    % DLC
        Na = 1;                                 % Air
        Nh = 2.354+0.363i;                      % AlTiC
        if Mode == 1
            PT1(1) = 530.599;
            PT1(2) = 850;
            PT1(3) = 1058.223;
            PT1(4) = 1221.336;
        %============================
            PT1_min(1) = 298.4;
            PT1_min(2) = 283.2;
            PT1_min(3) = 280.8;
            PT1_min(4) = 271;
```

```
            %=============================
                PT1_max(1) = 1378.4;
                PT1_max(2) = 1378.4;
                PT1_max(3) = 1378.6;
                PT1_max(4) = 1387.6;
            elseif Mode == 2
                PT2(1) = 879.494;
                PT2(2) = 1350.186;
                PT2(3) = 1672.807;
                PT2(4) = 1901.923;
             %============================
                PT2_min(1) = 434.6;
                PT2_min(2) = 428.8;
                PT2_min(3) = 406;
                PT2_min(4) = 398.8;
             %============================
                PT2_max(1) = 2083;
                PT2_max(2) = 2069;
                PT2_max(3) = 2090;
                PT2_max(4) = 2086.8;
            end
        elseif L == 650e-9
            Ng = 1.52;                          % Glass
            Ns = 4.014+0.309i;                  % Si amorphous
            Nd = 2.1631+0.0985i;                % DLC
            Na = 1;                             % Air
            Nh = 2.289+0.344i;                  % AlTiC
            if Mode == 1
                PT1(1) = 540.167;
                PT1(2) = 947.603;
                PT1(3) = 1262.077;
                PT1(4) = 1532.146;
            %============================
                PT1_min(1) = 364;
                PT1_min(2) = 338.6;
                PT1_min(3) = 330.2;
                PT1_min(4) = 317;
            %============================
                PT1_max(1) = 1961.6;
                PT1_max(2) = 1979.2;
                PT1_max(3) = 1971.2;
                PT1_max(4) = 1980.4;
            elseif Mode == 2
                PT2(1) = 970.224;
                PT2(2) = 1629.896;
                PT2(3) = 2133.666;
                PT2(4) = 2550.377;
             %============================
                PT2_min(1) = 572.4;
                PT2_min(2) = 559.6;
                PT2_min(3) = 517.8;
                PT2_min(4) = 508.8;
             %============================
                PT2_max(1) = 3188.6;
                PT2_max(2) = 3179.4;
                PT2_max(3) = 3206.6;
                PT2_max(4) = 3200.6;
            end
    end
%=======================================================
%=========        ASSIGN Rij,Tij        ===============
```

```
%=====================================================================
        n =[Ng,         % Glass
            Ns,         % Si
            Nd,         % DLC
            Ns,         % Si2
            Nd,         % DLC2
            Na,         % Air
            Nh];        % AlTiC
        for u = 1:length(n)
            for v = 1:length(n)
                r(u,v) = (n(u)-n(v))/(n(u)+n(v));
                t(u,v) = 2*n(u)/(n(u)+n(v));
            end
        end
%=====================================================================
%=======      DEFINE 1st composite layer       =========
%=====================================================================
%----DLC2------ 5
%----Air------- 6
%----AlTiC----- 7
        for u = 1:length(fh)
        Rdm = r(5,6);  % Beam which reflect from middle layer
        Rdb = r(6,7);  % Beam which reflect from bottom layer
        B = (2*pi*fh(u)*n(6))/L;    % BETA, Below r of composite 1
        rc1(u,1) = (Rdm+Rdb*(exp(2*i*B)))/(1+Rdm*Rdb*(exp(2*i*B)));
%=====================================================================
%=======      DEFINE 2nd composite layer       =========
%=====================================================================
%--Add layer2-- 4
%----DLC2------ 5
%----COMP1-----rc1
            A = (2*pi*d2*n(5))/L;   % ALPHA, Below r of material
            Rdm = r(4,5);      % Beam which reflect from middle layer
            Rdb = rc1(u,1);  % Beam which reflect from bottom layer
            rc2(u,1)=(Rdm+Rdb*(exp(2*i*A)))/(1+Rdm*Rdb*(exp(2*i*A)));
%=====================================================================
%=======      DEFINE 3rd composite layer       =========
%=====================================================================
%-----DLC1----- 3
%--Add layer2-- 4
%----COMP2-----rc2
            G = (2*pi*T2*n(4))/L;   % ALPHA, Below r of material
            Rdm = r(3,4);      % Beam which reflect from middle layer
            Rdb = rc2(u,1);  % Beam which reflect from bottom layer
            rc3(u,1)=(Rdm+Rdb*(exp(2*i*G)))/(1+Rdm*Rdb*(exp(2*i*G)));
%=====================================================================
%=======      DEFINE 4th composite layer       =========
%=====================================================================
%--Add layer1--2
%-----DLC1-----3
%----COMP2-----rc3
            O = (2*pi*d*n(3))/L;   % ALPHA, Below r of material
            Rdm = r(2,3);      % Beam which reflect from middle layer
            Rdb = rc3(u,1);    % Beam which reflect from bottom layer
            rc4(u,1)=(Rdm+Rdb*(exp(2*i*O)))/(1+Rdm*Rdb*(exp(2*i*O)));

%=====================================================================
%=======      DEFINE 5th composite layer       =========
%=====================================================================
%-----Glass---1
%--Add layer1--2
```

```
%-----COMP2------rc4
            Q = (2*pi*T*n(2))/L;   % ALPHA, Below r of material
            Rdm = r(1,2);     % Beam which reflect from middle layer
            Rdb = rc4(u,1);   % Beam which reflect from bottom layer
            rc5(u,1)=(Rdm+Rdb*(exp(2*i*Q)))/(1+Rdm*Rdb*(exp(2*i*Q)));
            Amp(u,1) = abs(rc5(u,1))^2;
            Phs(u,1) = angle(rc5(u,1));
        end
%=====================================================================
%======      NORMALIZED INTENSITY TO 0-2       =========
%=====================================================================
    AmpN = Amp-min(Amp);
    mN = 2/max(AmpN);
    AmpC_N2 = AmpN.*mN;
%=====================================================================
%======     MEASUREMENT LOOP   ========================
%=====================================================================
% Use intensity from measurement from each case to re-plot FH
        if MEA == 1
            PT = PT1;
            PT_min = PT1_min;
            PT_max = PT1_max;
            fhm = fhm1+SHF;
            MTXT = '1st';
        elseif MEA == 2
            PT = PT2;
            PT_min = PT2_min;
            PT_max = PT2_max;
            fhm = fhm2+SHF;
            MTXT = '2nd';
        elseif MEA == 0
            ac1 = 0;
            %==== Merge data from 1&2 measurement ===
            for a1 = 1:length(fhm1)
                fhmd(a1,1) = fhm1(a1);
                PTd(a1,1) = PT1(a1);
                PTd_min(a1,1) = PT1_min(a1);
                PTd_max(a1,1) = PT1_max(a1);
            end
            for a2 = length(fhm1)+1:length(fhm1)+length(fhm2)
                ac1 = ac1+1;
                fhmd(a2,1) = fhm2(ac1);
                PTd(a2,1) = PT2(ac1);
                PTd_min(a2,1) = PT2_min(ac1);
                PTd_max(a2,1) = PT2_max(ac1);
            end
            %==============================================
            %=== Sort intensity data by assending fh ===
            fhmdS = sort(fhmd);
            for as = 1:length(fhmd)
                for as2 = 1:length(fhmd)
                    if fhmdS(as) == fhmd(as2)
                        A_index(as,1) = as2;
                    end
                end
            end
            %=== Define all necessary input parameters ==
            for Is = 1:length(fhmd)
                PT(Is,1) = PTd(A_index(Is));
                PT_min(Is,1) = PTd_min(A_index(Is));
                PT_max(Is,1) = PTd_max(A_index(Is));
```

```
            end
            fhm = fhmdS+SHF;
            MTXT = 'ALL';
        end
        for m = 1:length(fhm)
            IP(m) = ((PT(m)-PT_min(m))/(PT_max(m)-PT_min(m)))*2;
            if IP(m) < 0
                IP(m) = 0;
            end
        end
        if FT_ON == 0
            break, end
%=====================================================
%==========    FITTING LOOP   ========================
%=====================================================
% Fit N&K which its intensity give nearest FH to measurement data
        CT = 0;
        Cf = 0;
        for u = FT_S:FT_ST
            CT = CT+1;
            mI = 200;
            for v = 1:round(max(fhm))+1+5
                Cf = Cf+1;
                fERR(Cf,1) = abs(AmpC_N2(v)-IP(u));
                if fERR(Cf,1)<mI
                    mI = fERR(Cf,1);
                    fhC = v-1;
                end
            end
            FHC(CT) = fhC;    % Find the FH of each intensity which
nearest to measured intensity
        end
        Sfhm = size(fhm(FT_S:FT_ST));
        SFHC = size(FHC);
        if Sfhm(1,1) ~= SFHC(1,1)
            FHC = FHC';
        end
        ERR = sum((fhm(FT_S:FT_ST)-FHC).^2);
        if LC == 1
            ERR1 = ERR;
            nb = n;
            IPB = IP;
        elseif LC == 2
            ERR2 = ERR;
            ng = n;
            IPG = IP;
        elseif LC == 3
            ERR3 = ERR;
            nr = n;
            IPR = IP;
        end

        end
        SERR = ERR1+ERR2+ERR3;
        if  SERR< mERR
            mERR = SERR;
            Tindex = T;
            dindex = d;
            Tindex2 = T2;
            dindex2 = d2;
            FHC2 = FHC;
```

```
        end
            end
        end
    end
end
if FT_ON == 1
%=====================================================================
%=========================   FOR PLOT   ==============================
%=====================================================================
%==================================================
%======     DEFINE 1st composite layer     =======
%==================================================
%----DLC-------3
%----Air-------4
%----AlTiC-----5
for LC = 1:length(WL)
    L = WL(LC);
    if LC == 1
        n = nb;
    elseif LC == 2
        n = ng;
    elseif LC == 3
        n = nr;
    end
        for u = 1:length(n)
            for v = 1:length(n)
                r(u,v) = (n(u)-n(v))/(n(u)+n(v));
                t(u,v) = 2*n(u)/(n(u)+n(v));
            end
        end
%==================================================
%======     DEFINE 1st composite layer     =======
%==================================================
%----DLC2------ 5
%----Air------- 6
%----AlTiC----- 7
        for u = 1:length(fh)
        Rdm = r(5,6);   % Beam which reflect from middle layer
        Rdb = r(6,7);   % Beam which reflect from bottom layer
        B = (2*pi*fh(u)*n(6))/L;    % BETA, Below r of composite 1
        rc1(u,1) = (Rdm+Rdb*(exp(2*i*B)))/(1+Rdm*Rdb*(exp(2*i*B)));
%==================================================
%======     DEFINE 2nd composite layer     =======
%==================================================
%--Add layer2-- 4
%----DLC2------ 5
%----COMP1-----rc1
        A = (2*pi*dindex2*n(5))/L;   % ALPHA, Below r of material
        Rdm = r(4,5);      % Beam which reflect from middle layer
        Rdb = rc1(u,1);    % Beam which reflect from bottom layer
        rc2(u,1) = (Rdm+Rdb*(exp(2*i*A)))/(1+Rdm*Rdb*(exp(2*i*A)));
%==================================================
%======     DEFINE 3rd composite layer     =======
%==================================================
%-----DLC1----- 3
%--Add layer2-- 4
%----COMP2-----rc2
         G = (2*pi*Tindex2*n(4))/L;   % ALPHA, Below r of material
         Rdm = r(3,4);      % Beam which reflect from middle layer
         Rdb = rc2(u,1);    % Beam which reflect from bottom layer
         rc3(u,1) = (Rdm+Rdb*(exp(2*i*G)))/(1+Rdm*Rdb*(exp(2*i*G)));
```

```
%================================================================
%======      DEFINE 4th composite layer        =========
%================================================================
%--Add layer1--2
%------DLC1-----3
%----COMP2-----rc3
            O = (2*pi*dindex*n(3))/L;  % ALPHA, Below r of material
            Rdm = r(2,3);      % Beam which reflect from middle layer
            Rdb = rc3(u,1);    % Beam which reflect from bottom layer
            rc4(u,1) = (Rdm+Rdb*(exp(2*i*O)))/(1+Rdm*Rdb*(exp(2*i*O)));
%================================================================
%======      DEFINE 5th composite layer        =========
%================================================================
%------Glass----1
%--Add layer1--2
%----COMP2-----rc4
            Q = (2*pi*Tindex*n(2))/L;  % ALPHA, Below r of material
            Rdm = r(1,2);      % Beam which reflect from middle layer
            Rdb = rc4(u,1);    % Beam which reflect from bottom layer
            rc5(u,1) = (Rdm+Rdb*(exp(2*i*Q)))/(1+Rdm*Rdb*(exp(2*i*Q)));
            Amp(u,1) = abs(rc5(u,1))^2;
            Phs(u,1) = angle(rc5(u,1));
        end
%================================================================
%======      NORMALIZED INTENSITY TO 0-2        =========
%================================================================
    AmpN = Amp-min(Amp);
    mN = 2/max(AmpN);
    AmpP_N2 = AmpN.*mN;
    if L == 450e-9
        Cb = 'b';
        Cb2 = 'b*';
        AMPP_NB = AmpP_N2;
    elseif L == 550e-9
        Cg = 'g';
        Cg2 = 'g*';
        AMPP_NG = AmpP_N2;
    elseif L == 650e-9
        Cr = 'r';
        Cr2 = 'r*';
        AMPP_NR = AmpP_N2;
    end
end
if SC == 20
    S_arr1 = [1,10,20];
    S_arr2 = [2,12,22];
    GSEN = 0.1929;
elseif SC == 50
    S_arr1 = [1,10,20,30,40,50];
    S_arr2 = [2,12,22,32,42,52];
    GSEN = 0.6013;
end
SB = sum(abs(AMPP_NB(S_arr2)-AMPP_NB(S_arr1)));
SG = sum(abs(AMPP_NG(S_arr2)-AMPP_NG(S_arr1)));
SR = sum(abs(AMPP_NR(S_arr2)-AMPP_NR(S_arr1)));
SEN = SB+SG+SR;
SENP = ((SEN-GSEN)/GSEN)*100;
fh = fh.*10^9;
plot(fh(1:PLD),AMPP_NB(1:PLD),Cb,fhm,IPB,Cb2,fh(1:PLD),AMPP_NG(1:PLD)
,Cg,fhm,IPG,Cg2,fh(1:PLD),AMPP_NR(1:PLD),Cr,fhm,IPR,Cr2)
if Mode == 1
```

```
    legend(['DLC = ',num2str(dindex*10^9),' nm ' ,'Si =
',num2str(Tindex*10^9),' nm'])
elseif Mode == 2
    legend(['DLC1 = ',num2str(dindex*10^9),' nm, ' ,'Si1 =
',num2str(Tindex*10^9),' nm, DLC2 = ',num2str(dindex2*10^9),' nm, Si2
= ',num2str(Tindex2*10^9),' nm'])
end
ylabel('Normalized intensity')
xlabel('FH(nm)')
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%% END PROGRAM %%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

สำนักงานคณะกรรมการวิจัยแห่งชาติ
ห้องสมุดงานวิจัย

ประวัติผู้เขียนวิทยานิพนธ์

นายกรกช เพชรดี เกิดเมื่อวันที่ 3 มิถุนายน พ.ศ. 2528 ที่กรุงเทพมหานคร สำเร็จการศึกษาปริญญาวิศวกรรมศาสตรบัณฑิต สาขาวิชาวิศวกรรมการบินและอวกาศยาน คณะวิศวกรรมศาสตร์ มหาวิทยาลัยเกษตรศาสตร์ ปีการศึกษา 2549 และได้เข้าศึกษาต่อในหลักสูตรวิศวกรรมศาสตรมหาบัณฑิต สาขาวิชาวิศวกรรมเครื่องกล คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัยในปีการศึกษา 2551