In[•]:=
```
(*Heat transfer with ambiant air*)
ϕ = 10^-3;
Cpa = 1000;
β = 1/(273.15 + 30);
σ = 5.67 × 10^-8;
λa = 0.026;
μa = 1.9 × 10^-5;
ρa = 1.2 ;
νa = μa / ρa;
ϵ = 0.85;
αa = λa/(ρa Cpa);
Tair = 273.15 + 20;
Tnerf = 273.15 + 50;
Pr = νa / αa;
Ray = (9.81 β ϕ^3 (Tnerf - Tair))/(νa αa);
Nu = ((0.6 + 0.387 Ray^(1/6))/(1 + (0.559/Pr)^(9/16))^(8/27))^2 ;
(Nu λa)/ϕ
(π d 1)/((π d^2)/4 1)
(2 × 1 × 1)/(1 × 1 d)
σ (Tnerf^2 + Tair^2) (Tnerf + Tair)
```

Out[•]=
```
20.2338
```

Out[•]=
$$\frac{4}{d}$$

Out[•]=
$$\frac{2}{d}$$

Out[•]=
```
6.65208
```

```
λ = 0.76;
ρ = 1030;
h = 2 × 27;
Cp = 3500;
α = λ / (ρ Cp);
ϕ = 10^-3;
L = 0.5 × 10^-2;
dp = 400 × 10^-6; (*diamètre du pulse*)
tp = 10 × 400 × 10^-6; (*durée du pulse*)
f = 10; (*fréquence de pulse*)
Ep = 4 × 10^-3; (*énergie du pulse*)
xp = (L - dp) / 2; (*position axiale du début du pulse*)
Vt = dp π ϕ^2 / 4; (*volume de la tranche*)
δ = 0.35; (*fraction de la tranche du
 nerf cylindrique dans laquelle le pulse arrive*)
e[t_] = Ep / (tp δ Vt) If[Mod[t, 1/f] < tp, 1, 0];
m = 30;
Troom = 20;
Tini = 28;
```

In[•]:=
```
ratio = L / ϕ;
Δ = ϕ / m;
Bi = Δ h / λ;
αt = α / Δ^2;
L / Δ
n = Round[L / Δ, 1];
npd = Round[xp / Δ, 1];
npf = Round[(xp + dp) / Δ, 1];
mpd = Round[(ϕ - dp) / Δ, 1];
```

Out[•]=
```
150.
```

In[•]:=
```
index[x_] := If[x ≤ n/2,
    Round[(m - 1) - (x - npd) ((m - 1) - mpd)/(n/2 - npd), 1], Round[mpd + (x - n/2) ((m - 1) - mpd)/(npf - n/2), 1]];
Table[index[x], {x, npd, npf}]
```

Out[•]=
```
{29, 27, 25, 24, 22, 20, 18, 20, 22, 24, 25, 27, 29}
```

In[•]:=
```
mpd
```

Out[•]=
```
18
```

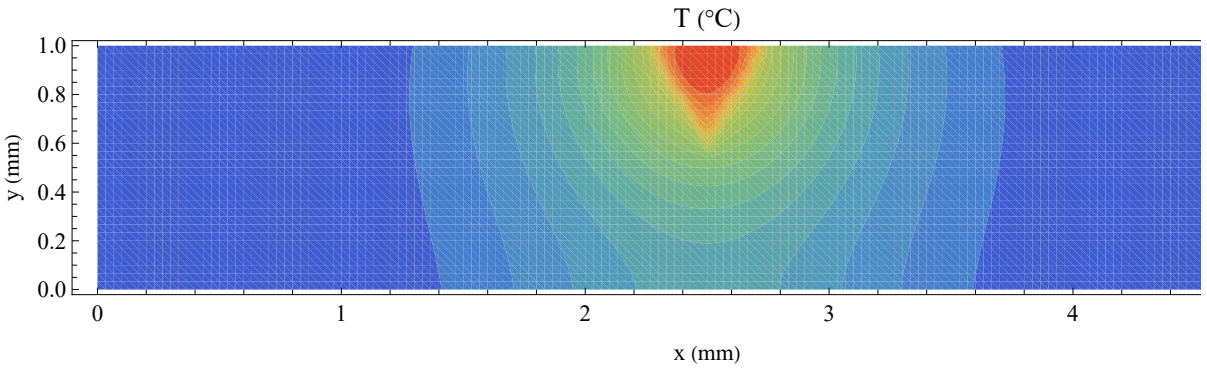
In[•]:=
```
inc = {};
For[i = 1, i < n, i++,
 inc = Join[inc, Table[T[i, j][t], {j, 1, m - 1}]];
]
ci = {};
For[i = 1, i < npd, i++,
 ci = Join[ci, Table[T[i, j][0] == Tini, {j, 1, m - 1}]];
]
For[i = npd, i ≤ npf, i++,
 ci = Join[ci, Table[T[i, j][0] == Tini, {j, 1, mpd - 1}]];
 ci = Join[ci, Table[T[i, j][0] == Tini, {j, mpd, m - 1}]];
]
For[i = npf + 1, i < n, i++,
 ci = Join[ci, Table[T[i, j][0] == Tini, {j, 1, m - 1}]];
]
bc = Table[T[i, 0][t] → (T[i, 1][t] + Bi Troom)/(1 + Bi), {i, 1, n - 1}];
bc = Join[bc, Table[T[i, m][t] → (T[i, m - 1][t] + Bi Troom)/(1 + Bi), {i, 1, n - 1}]];
bc = Join[bc, Table[T[0, j][t] → T[1, j][t], {j, 1, m - 1}]];
bc = Join[bc, Table[T[n, j][t] → T[n - 1, j][t], {j, 1, m - 1}]];
```

```
In[•]:= eq = {};
For[i = 1, i < npd, i++,
  eq = Join[eq, Table[T[i, j]'[t] == αt (T[i + 1, j][t] + T[i - 1, j][t] - 2 T[i, j][t] +
         T[i, j + 1][t] + T[i, j - 1][t] - 2 T[i, j][t]), {j, 1, m - 1}]];
 ];
For[i = npd, i ≤ npf, i++,
  eq = Join[eq,
    Table[T[i, j]'[t] == αt (T[i + 1, j][t] + T[i - 1, j][t] - 2 T[i, j][t] + T[i, j + 1][t] +
        T[i, j - 1][t] - 2 T[i, j][t]), {j, 1, index[i] - 1}]];
  eq = Join[eq, Table[T[i, j]'[t] ==
      αt (T[i + 1, j][t] + T[i - 1, j][t] - 2 T[i, j][t] + T[i, j + 1][t] + T[i, j - 1][t] -
          2 T[i, j][t]) + 1/(ρ Cp) Ep/(tp δ Vt) If[Mod[t, 1/f] < tp, 1, 0], {j, index[i], m - 1}]];
 ];
For[i = npf + 1, i < n, i++,
  eq = Join[eq, Table[T[i, j]'[t] == αt (T[i + 1, j][t] + T[i - 1, j][t] - 2 T[i, j][t] +
         T[i, j + 1][t] + T[i, j - 1][t] - 2 T[i, j][t]), {j, 1, m - 1}]];
 ];
eqfull = Join[eq, ci] /. bc;
sol = NDSolve[eqfull, inc, {t, 0, 3}][[1]];

In[•]:= Contour[temps_] := (
  datafull = {};
  bcbis = {T[0, 0][t] → T[0, 1][t], T[0, m][t] → T[0, m - 1][t],
    T[n, 0][t] → T[n, 1][t], T[n, m][t] → T[n, m - 1][t]};
  For[i = 0, i ≤ n, i++,
   datafull = Join[datafull, Table[
       {1000 i Δ, 1000 j Δ, T[i, j][t] /. bcbis /. bc /. sol /. t → temps}, {j, 0, m}]];
  ];
  buff = ListContourPlot[datafull, Frame → True ,
    PlotRange → All, Axes → False, FrameLabel → {"x (mm)", "y (mm)"},
    BaseStyle → {FontFamily → "Times", FontSize → 12}, ColorFunctionScaling → False,
    PlotRange → All, InterpolationOrder → 3, Contours → 20,
    ColorFunction → ColorData[{"Rainbow", {Troom, 60}}], ImageSize → 700,
    AspectRatio → m/n, PlotLabel → "T (°C)", ContourLines → False];
  Legended[buff, BarLegend[{"Rainbow", {Troom, 60}}]]
 )
```

```
Contour[2 + tp]
```

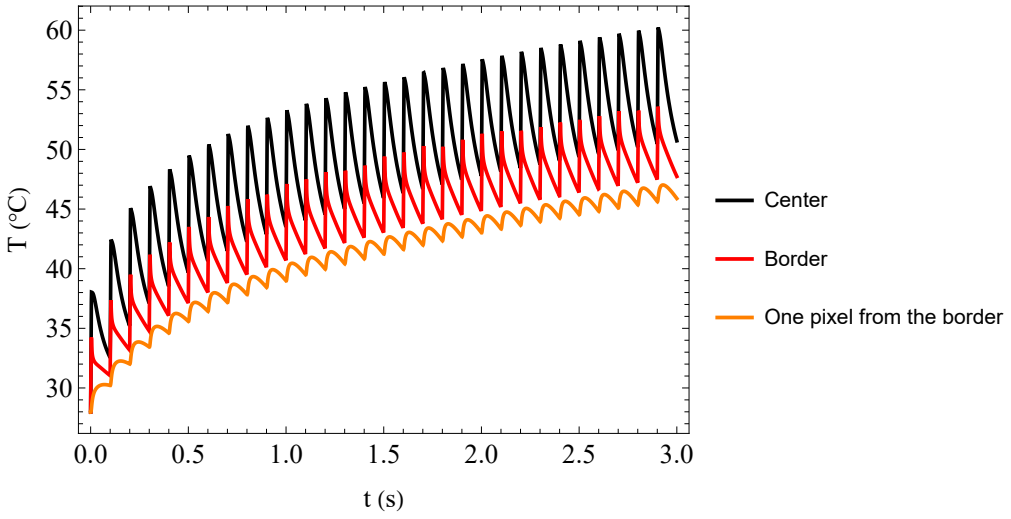
Out[•]=



In[•]:=

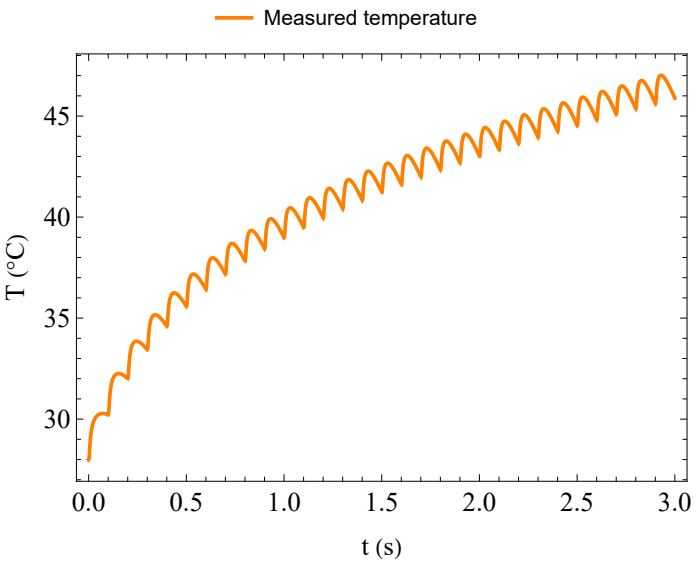
```
pix = 0.073 × 10^-3;
Tcentre[t_] = T[n / 2, m][t] /. bc /. sol;
Tbord[t_] = T[npf, m][t] /. bc /. sol;
T1pix[t_] = T[npf + Floor[pix / Δ], m][t] /. bc /. sol;
Plot[Tcentre[t], {t, 0, 3}, Axes → False, Frame → True,
  PlotRange → All, AspectRatio → 0.7, FrameLabel → {"t (s)", "T (°C)"},
  BaseStyle → {FontFamily → "Times", FontSize → 14},
  PlotStyle → {Black, Thickness[0.006]} ,
  PlotLegends → Placed[LineLegend[{"Center"}, LabelStyle → {11}], Right]];
Plot[Tbord[t], {t, 0, 3}, Axes → False, Frame → True, PlotRange → All, AspectRatio → 0.7,
  FrameLabel → {"t (s)", "T (°C)"}, BaseStyle → {FontFamily → "Times", FontSize → 14},
  PlotStyle → {Red, Thickness[0.006]} ,
  PlotLegends → Placed[LineLegend[{"Border"}, LabelStyle → {11}], Right]];
Plot[T1pix[t], {t, 0, 3}, Axes → False, Frame → True, PlotRange → All, AspectRatio → 0.7,
  FrameLabel → {"t (s)", "T (°C)"}, BaseStyle → {FontFamily → "Times", FontSize → 14},
  PlotStyle → {Orange, Thickness[0.006]} , PlotLegends →
   Placed[LineLegend[{"One pixel from the border"}, LabelStyle → {11}], Right]];
Show[%%%, %%, %]
```

Out[•]=



In[•]:=
```
Plot[T1pix[t], {t, 0, 3}, Axes → False, Frame → True, PlotRange → All, AspectRatio → 0.7,
 FrameLabel → {"t (s)", "T (°C)"}, BaseStyle → {FontFamily → "Times", FontSize → 14},
 PlotStyle → {Orange, Thickness[0.006]} ,
 PlotLegends → Placed[LineLegend[{"Measured temperature"}, LabelStyle → {11}], Top]]
```

Out[•]=

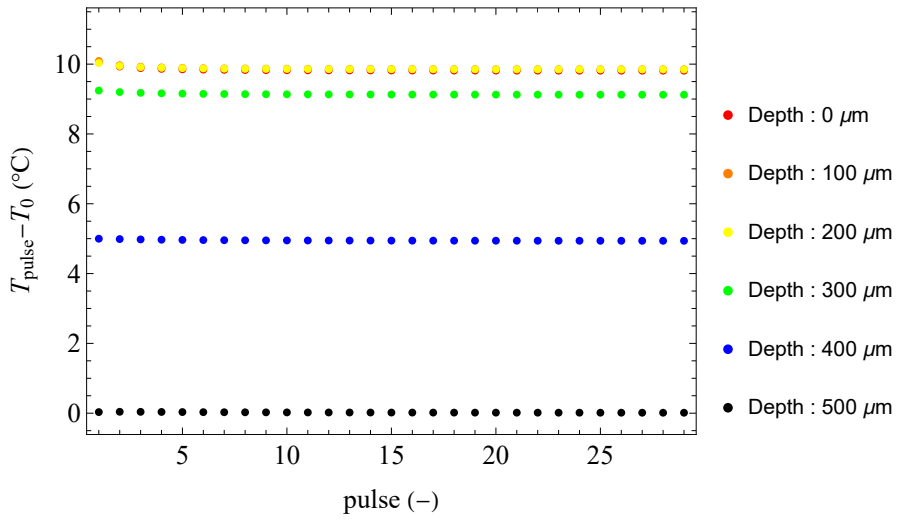


In[•]:=
```
(*nouveaux graphes*)
```

In[•]:=
```
depth = 0;(*profondeur en microns*)
Temp[t_] = T[n/2, m - Round[depth 10^-6 / Δ, 1]][t] /. bc /. sol;
data0 = Table[{i, Temp[(i - 1) 1/f + tp] - Temp[(i - 1) 1/f]}, {i, 1, 3/(1/f) - 1}];
depth = 100;(*profondeur en microns*)
Temp[t_] = T[n/2, m - Round[depth 10^-6 / Δ, 1]][t] /. bc /. sol;
data100 = Table[{i, Temp[(i - 1) 1/f + tp] - Temp[(i - 1) 1/f]}, {i, 1, 3/(1/f) - 1}];
depth = 200;(*profondeur en microns*)
Temp[t_] = T[n/2, m - Round[depth 10^-6 / Δ, 1]][t] /. bc /. sol;
data200 = Table[{i, Temp[(i - 1) 1/f + tp] - Temp[(i - 1) 1/f]}, {i, 1, 3/(1/f) - 1}];
depth = 300;(*profondeur en microns*)
Temp[t_] = T[n/2, m - Round[depth 10^-6 / Δ, 1]][t] /. bc /. sol;
data300 = Table[{i, Temp[(i - 1) 1/f + tp] - Temp[(i - 1) 1/f]}, {i, 1, 3/(1/f) - 1}];
depth = 400;(*profondeur en microns*)
Temp[t_] = T[n/2, m - Round[depth 10^-6 / Δ, 1]][t] /. bc /. sol;
data400 = Table[{i, Temp[(i - 1) 1/f + tp] - Temp[(i - 1) 1/f]}, {i, 1, 3/(1/f) - 1}];
depth = 500;(*profondeur en microns*)
Temp[t_] = T[n/2, m - Round[depth 10^-6 / Δ, 1]][t] /. bc /. sol;
data500 = Table[{i, Temp[(i - 1) 1/f + tp] - Temp[(i - 1) 1/f]}, {i, 1, 3/(1/f) - 1}];
```

In[•]:=
```
ListPlot[data0, Axes → False, Frame → True, PlotRange → All,
  AspectRatio → 0.7, FrameLabel → {"pulse (-)", "T_pulse-T_0 (°C)"},
  BaseStyle → {FontFamily → "Times", FontSize → 14},
  PlotStyle → {Red, Thickness[0.006]} , PlotLegends → Placed[LineLegend[
     {StringJoin["Depth : ", ToString[0], " μm"]}, LabelStyle → {11}], Right]];
ListPlot[data100, Axes → False, Frame → True, PlotRange → All,
  AspectRatio → 0.7, FrameLabel → {"pulse (-)", "T_pulse-T_0 (°C)"},
  BaseStyle → {FontFamily → "Times", FontSize → 14},
  PlotStyle → {Orange, Thickness[0.006]} , PlotLegends → Placed[LineLegend[
     {StringJoin["Depth : ", ToString[100], " μm"]}, LabelStyle → {11}], Right]];
ListPlot[data200, Axes → False, Frame → True, PlotRange → All,
  AspectRatio → 0.7, FrameLabel → {"pulse (-)", "T_pulse-T_0 (°C)"},
  BaseStyle → {FontFamily → "Times", FontSize → 14},
  PlotStyle → {Yellow, Thickness[0.006]} , PlotLegends → Placed[LineLegend[
     {StringJoin["Depth : ", ToString[200], " μm"]}, LabelStyle → {11}], Right]];
ListPlot[data300, Axes → False, Frame → True, PlotRange → All,
  AspectRatio → 0.7, FrameLabel → {"pulse (-)", "T_pulse-T_0 (°C)"},
  BaseStyle → {FontFamily → "Times", FontSize → 14},
  PlotStyle → {Green, Thickness[0.006]} , PlotLegends → Placed[LineLegend[
     {StringJoin["Depth : ", ToString[300], " μm"]}, LabelStyle → {11}], Right]];
ListPlot[data400, Axes → False, Frame → True, PlotRange → All,
  AspectRatio → 0.7, FrameLabel → {"pulse (-)", "T_pulse-T_0 (°C)"},
  BaseStyle → {FontFamily → "Times", FontSize → 14},
  PlotStyle → {Blue, Thickness[0.006]} , PlotLegends → Placed[LineLegend[
     {StringJoin["Depth : ", ToString[400], " μm"]}, LabelStyle → {11}], Right]];
ListPlot[data500, Axes → False, Frame → True, PlotRange → All,
  AspectRatio → 0.7, FrameLabel → {"pulse (-)", "T_pulse-T_0 (°C)"},
  BaseStyle → {FontFamily → "Times", FontSize → 14},
  PlotStyle → {Black, Thickness[0.006]} , PlotLegends → Placed[LineLegend[
     {StringJoin["Depth : ", ToString[500], " μm"]}, LabelStyle → {11}], Right]];
Show[%%%%%%, %%%%%, %%%%, %%%, %%, %, PlotRange → {All, {0, 11}}]
```

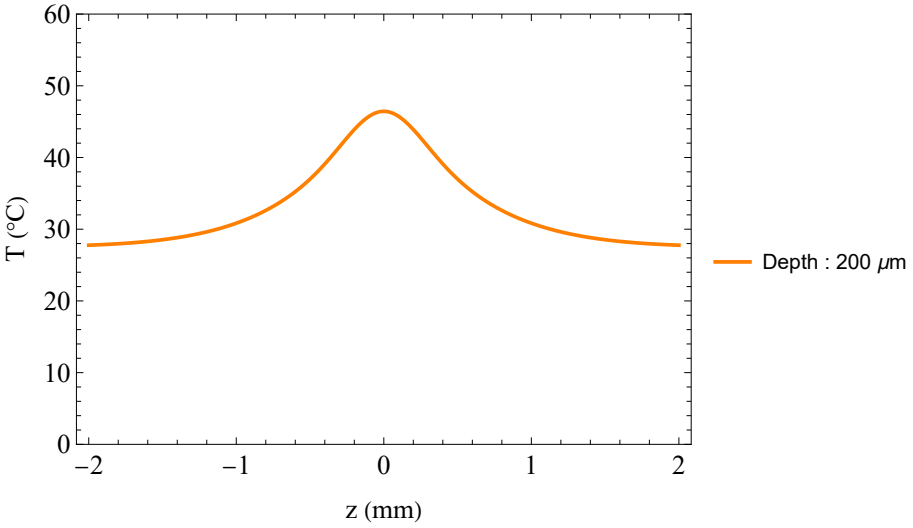
Out[•]=



In[•]:=
```
profil[npulse_, depth_] := (
  dist = 2 × 10^-3;
  time1 = npulse / f;
  data =
   Table[{10^3 (i - n / 2) Δ, T[i, m - Round[depth 10^-6 / Δ, 1]][t] /. bc /. sol /. t → time1},
    {i, Round[n / 2 - dist / Δ, 1], Round[n / 2 + dist / Δ, 1]}];
  grprofile[npulse] = ListPlot[data, Joined → True, Axes → False, Frame → True,
    PlotRange → {All, {0, 60}}, AspectRatio → 0.7, FrameLabel → {"z (mm)", "T (°C)"},
    BaseStyle → {FontFamily → "Times", FontSize → 14},
    PlotStyle → {Orange, Thickness[0.006]} , PlotLegends → Placed[LineLegend[
       {StringJoin["Depth : ", ToString[depth], " μm"]}, LabelStyle → {11}], Right]]
 )
```

In[•]:=
```
profil[21, 200]
prof[z_] = Interpolation[data][z];
dersec[z_] = prof''[z];
width = 2 z /. FindRoot[dersec[z], {z, 0.1}];
(prof[0] - prof[width/2]) / (width/2)
```

Out[•]=



Out[•]=
```
16.3853
```

```
(* Spatial gradient computation based on FWHM definition *)
gradientbis[npulse_, depth_] :=
 (
  profil[npulse, depth];
  prof[z_] = Interpolation[data][z];
  Thalf = (prof[0] + prof[data[[1, 1]]])/2;
  width = 2 Abs[z /. FindRoot[prof[z] - Thalf, {z, 0.1}]];
  (prof[0] - prof[data[[1, 1]]])/width
 )

(* Spatial gradient computation based on inflexion points,
which are close to HM points *)
gradient[npulse_, depth_] :=
 (
  profil[npulse, depth];
  prof[z_] = Interpolation[data][z];
  dersec[z_] = prof''[z];
  width = 2 z /. FindRoot[dersec[z], {z, 0.1}];
  (prof[0] - prof[width/2])/(width/2)
 )
```

In[•]:=
```
gradient[30, 400]
gradientbis[30, 400]
```

Out[•]=
```
11.3495
```

Out[•]=
```
13.1915
```

In[•]:=
```
tevgrad[depth_] :=
 (
  Table[{i, gradientbis[i, depth]}, {i, 1, 30}]
 )
```

In[•]:=
```
data0 = tevgrad[0];
data100 = tevgrad[100];
data200 = tevgrad[200];
data300 = tevgrad[300];
data400 = tevgrad[400];
```

In[•]:=
```
ListPlot[data0, Joined → False, Axes → False, Frame → True,
  PlotRange → All, AspectRatio → 0.7, FrameLabel → {"pulse (-)", "T (°C/mm)"},
  BaseStyle → {FontFamily → "Times", FontSize → 14},
  PlotStyle → {Red, Thickness[0.006]} , PlotLegends → Placed[LineLegend[
    {StringJoin["Depth : ", ToString[0], " μm"]}, LabelStyle → {11}], Right]];
(*change Joined→ False to True if willing to have full curve*)
ListPlot[data100, Joined → False, Axes → False, Frame → True, PlotRange → All,
  AspectRatio → 0.7, FrameLabel → {"pulse (-)", "gradT (°C/mm)"},
  BaseStyle → {FontFamily → "Times", FontSize → 14},
  PlotStyle → {Orange, Thickness[0.006]} , PlotLegends → Placed[LineLegend[
    {StringJoin["Depth : ", ToString[100], " μm"]}, LabelStyle → {11}], Right]];
ListPlot[data200, Joined → False, Axes → False, Frame → True, PlotRange → All,
  AspectRatio → 0.7, FrameLabel → {"pulse (-)", "gradT (°C/mm)"},
  BaseStyle → {FontFamily → "Times", FontSize → 14},
  PlotStyle → {Yellow, Thickness[0.006]} , PlotLegends → Placed[LineLegend[
    {StringJoin["Depth : ", ToString[200], " μm"]}, LabelStyle → {11}], Right]];
ListPlot[data300, Joined → False, Axes → False, Frame → True, PlotRange → All,
  AspectRatio → 0.7, FrameLabel → {"pulse (-)", "gradT (°C/mm)"},
  BaseStyle → {FontFamily → "Times", FontSize → 14},
  PlotStyle → {Green, Thickness[0.006]} , PlotLegends → Placed[LineLegend[
    {StringJoin["Depth : ", ToString[300], " μm"]}, LabelStyle → {11}], Right]];
ListPlot[data400, Joined → False, Axes → False, Frame → True, PlotRange → All,
  AspectRatio → 0.7, FrameLabel → {"pulse (-)", "gradT (°C/mm)"},
  BaseStyle → {FontFamily → "Times", FontSize → 14},
  PlotStyle → {Blue, Thickness[0.006]} , PlotLegends → Placed[LineLegend[
    {StringJoin["Depth : ", ToString[400], " μm"]}, LabelStyle → {11}], Right]];
Show[%%%%%, %%%%, %%%, %%, %, PlotRange → All]
```

Out[•]=