Supporting Information

Complete stress release in monolayer ALD-Al_2O_3 film based on mechanical equilibrium homeostasis to realize a bending radius of 1mm

Ze Li[1], Zhenyu Wang[1], Ziqiang Chen[1], Jing Feng[1], Jintao Wang[1], Siyu Fan[1], Hongbo Sun[1,2], and Yu Duan[1]*

1 State Key Laboratory of Integrated Optoelectronics, College of Electronic Science and Engineering, Jilin University, Changchun130012, China

2 State Key Laboratory of Precision Measurement Technology and Instruments, Department of Precision Instrument, Tsinghua University, Haidian, Beijing 100084, China

*Corresponding author. E-mail: duanyu@jlu.edu.cn

1、MATLAB image processing and curvature calculation code：

```
im=imread('ps.png');
im=rgb2gray(im);
thresh = graythresh(im);
im=im2bw(im,thresh);
set(0,'defaultfigurecolor','w')
imshow(im)
[y,x]=find(im==0);
y=max(y)-y;
y=fliplr(y);
plot(x,y,'r.','Markersize', 2);
disp(' Please click on the two vertices (upper left and lower right points) of the actual coordinate box in Figrure, i.e. points A and B. ');
[Xx,Yy]=ginput(2);
min_x=input(' ')
max_x=input(' ')
min_y=input(')
max_y=input(' ')
x=(x-Xx(1))*(max_x-min_x)/(Xx(2)-Xx(1))+min_x;
```

```
y=(y-Yy(1))*(min_y-max_y)/(Yy(2)-Yy(1))+max_y;
plot(x,y,'r.','Markersize', 2);
axis([min_x,max_x,min_y,max_y])
rate_x=0.08;
rate_y=0.05;
[x_uni,index_x_uni]=unique(x);
x_uni(1:floor(length(x_uni)*rate_x))=[];
x_uni(floor(length(x_uni)*(1-rate_x)):end)=[];
index_x_uni(1:floor(length(index_x_uni)*rate_x))=[];
index_x_uni(floor(length(index_x_uni)*(1-rate_x)):end)=[];
[mxu,~]=size(x_uni);
[mx,~]=size(x);
for ii=1:mxu
    if ii==mxu
        ytemp=y(index_x_uni(ii):mx);
    else
        ytemp=y(index_x_uni(ii):index_x_uni(ii+1));
    end
    threshold1=mean(ytemp)-std(ytemp);
    threshold2=mean(ytemp)+std(ytemp);
    ytemp(find(ytemp<threshold1))=[];
    ytemp(find(ytemp>threshold2))=[];
    thresholdy=(max_y-min_y)*rate_y;
    ytemp(find(ytemp>max_y-thresholdy))=[];
    ytemp(find(ytemp<min_y+thresholdy))=[];
    y_uni(ii)=mean(ytemp);
end
x_uni(find(isnan(y_uni)))=[];
y_uni(find(isnan(y_uni)))=[];
figure,plot(x_uni,y_uni),title(' The scan curve obtained after processing ')
axis([min_x,max_x,min_y,max_y])
curve_val(1,:)=x_uni';
curve_val(2,:)=y_uni;
[p,s]=polyfit(curve_val(1,:),curve_val(2,:),4);
[y_fit,DELTA]=polyval(p,x_uni,s);
figure,plot(x_uni,y_fit),title(' The fitted curve ')
axis([min_x,max_x,min_y,max_y])

for i=1:(length(x_uni)-1)
   dx(i)=x_uni(i+1)-x_uni(i);
   dy(i)=y_fit(i+1)-y_fit(i);
   dddy(i)= dy(i)/dx(i);
end
```

```
for i = 1 : (length(x_uni)-2)
    ddx(i) = dx(i+1) - dx(i);
    ddy(i) = dy(i+1) - dy(i);
    K(i)=abs((dx(i)*ddy(i)-dy(i)*ddx(i)))/((dx(i)*dx(i)+dy(i)*dy(i))^1.5);
end
K_d = 1./K;
figure(4);
plot(x_uni,y_fit);
axis([0 2.5 -0.2 1.2]);
```

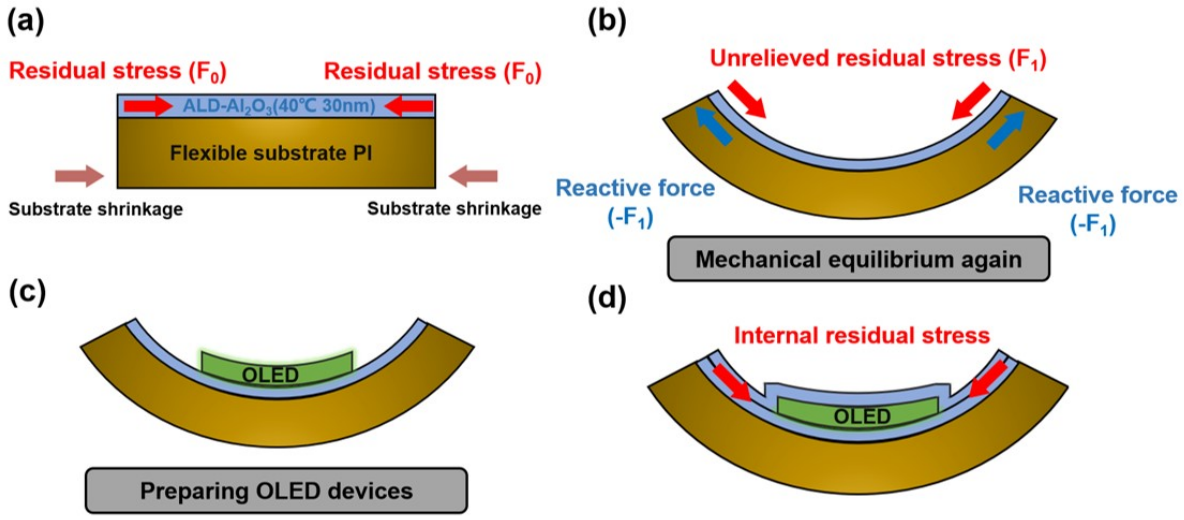

Fig. S1 Schematic diagram of normal growth ALD-Al_2O_3. (a) Deposition of ALD-Al_2O_3 on the PI substrate surface; (b) inward curling of the sample due to compressive residual stress; (c) OLED device preparation after reaching mechanical equilibrium; (d) numerous residual stresses inside the device after top encapsulation.

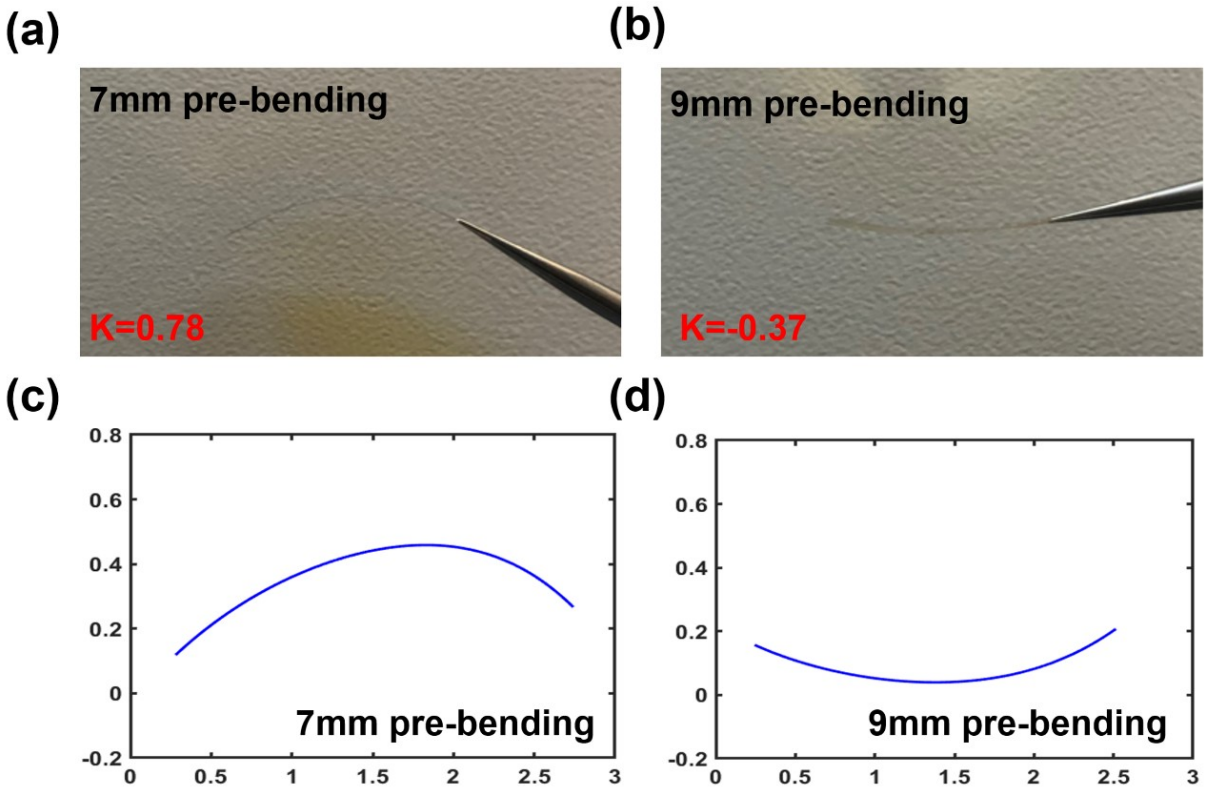

Fig. S2 (a-b) Cross-sectional contours and curvature of ALD-Al_2O_3 prepared by 7mm and 9mm pre-bending; (c-d) Curves after MATLAB image processing.

Table S1. Data of cross-sectional curvature with different heat treatment times for multiple sets of samples prepared by 5-mm pre-bending

Heat treatment time (min)	Curvature (mm^{-1})				
0	1.138	1.138	1.137	1.138	1.139
5	0.738	0.738	0.737	0.737	0.739
10	0.336	0.336	0.335	0.336	0.337
20	0.005	0.004	0.004	0.005	0.005
30	0.005	0.004	0.004	0.004	0.005

Table S2. Data of cross-sectional curvature with different heat treatment times for multiple groups of samples prepared by 7mm pre-bending

Heat treatment time (min)	Curvature(cm^{-1})				
0	0.784	0.783	0.783	0.784	0.785
5	0.339	0.338	0.339	0.340	0.340
10	0.243	0.243	0.243	0.243	0.245
20	0.189	0.188	0.190	0.191	0.191
30	0.193	0.192	0.192	0.193	0.194

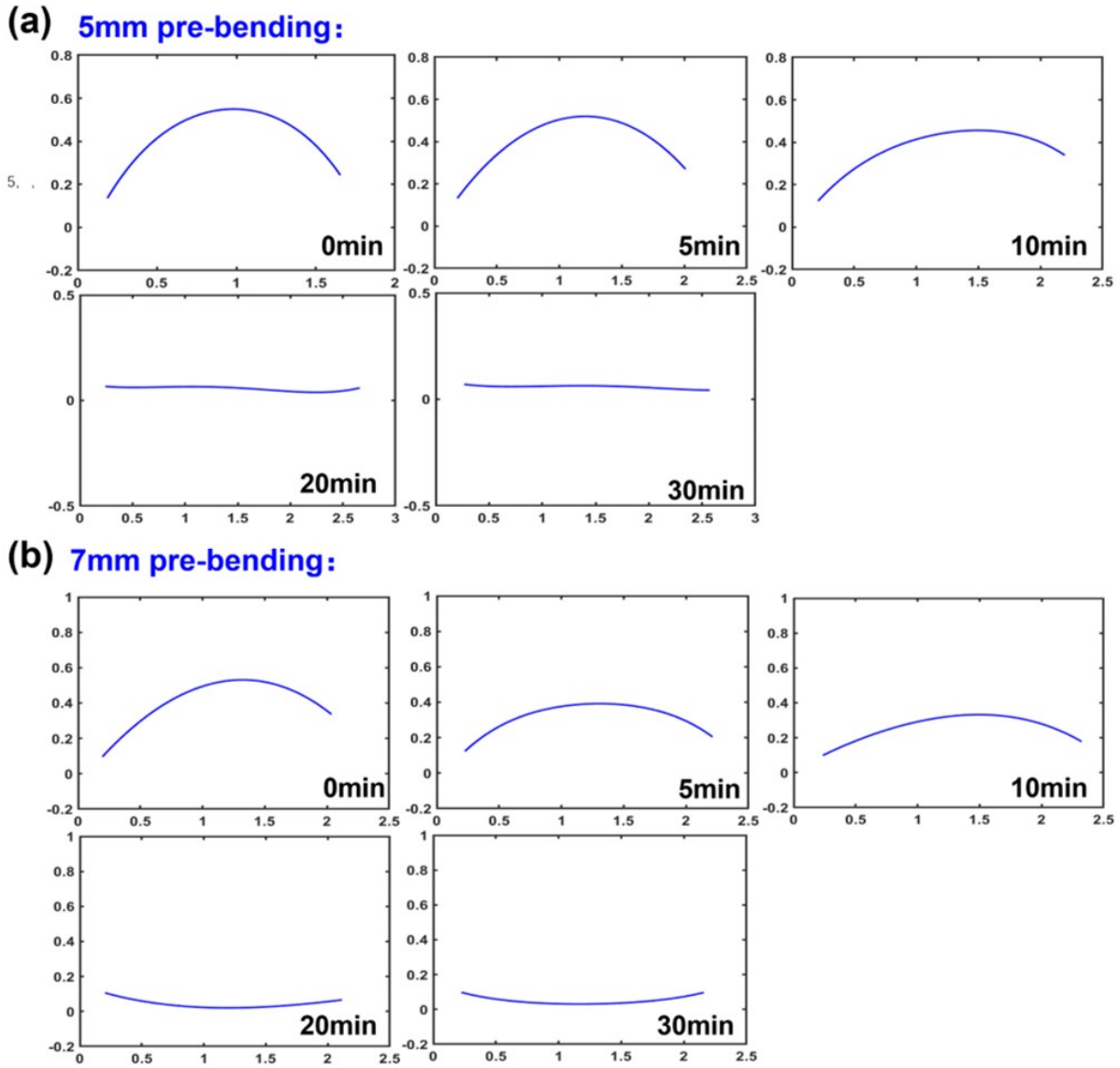

Fig. S3 (a-b) Cross-sectional contour curves of samples prepared by 7mm and 9mm pre-bending process with different heat treatment times after MATLAB image processing

Table S3. Crack density data from optical microscopy.

Sample	Crack density (mm^{-1})	Sample	Crack density (mm^{-1})
Normal growth	36.2	Normal growth/Heat treatment	30.5
3-mm pre-bending	10.5	3-mm pre-bending/ Heat treatment	0
5-mm pre-bending	16.1	5-mm pre-bending/ Heat treatment	0
7-mm pre-bending	30.2	7-mm pre-bending/ Heat treatment	20.6
9-mm pre-bending	34.8	9-mm pre-bending/ Heat treatment	24.2

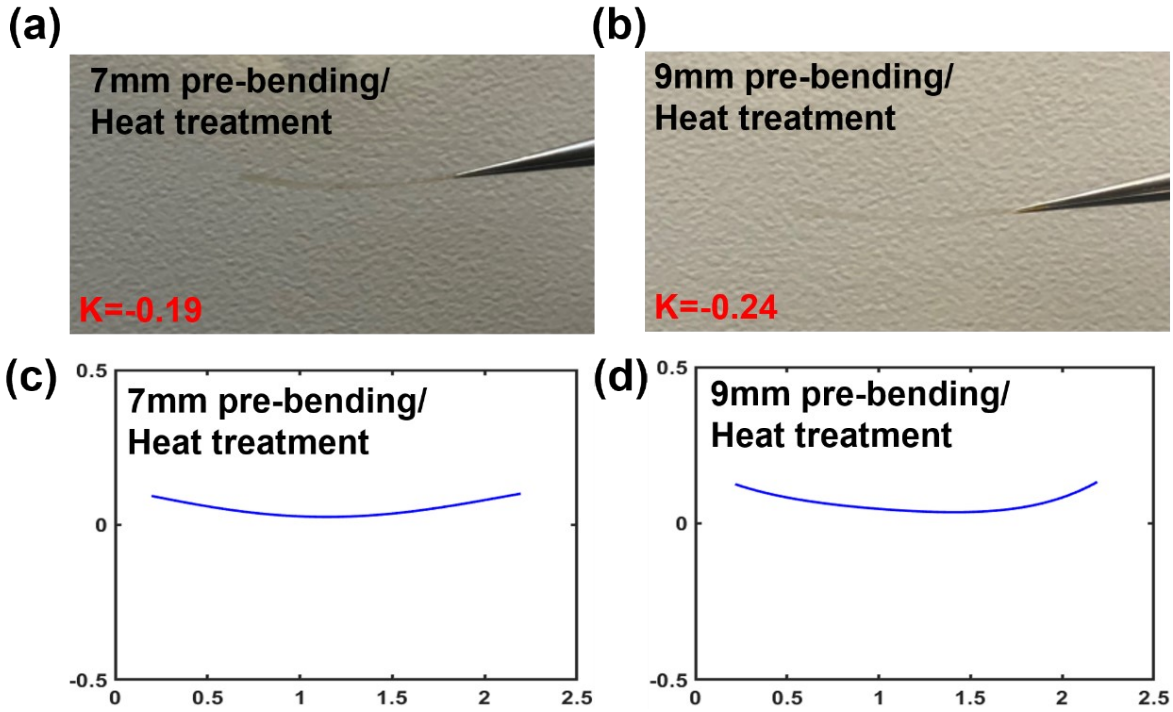

Fig. S4 (a-b) Cross-sectional contours and curvature of 7mm and 9mm pre-bending prepared samples after heat treatment; (d-f) Curves after MATLAB image processing

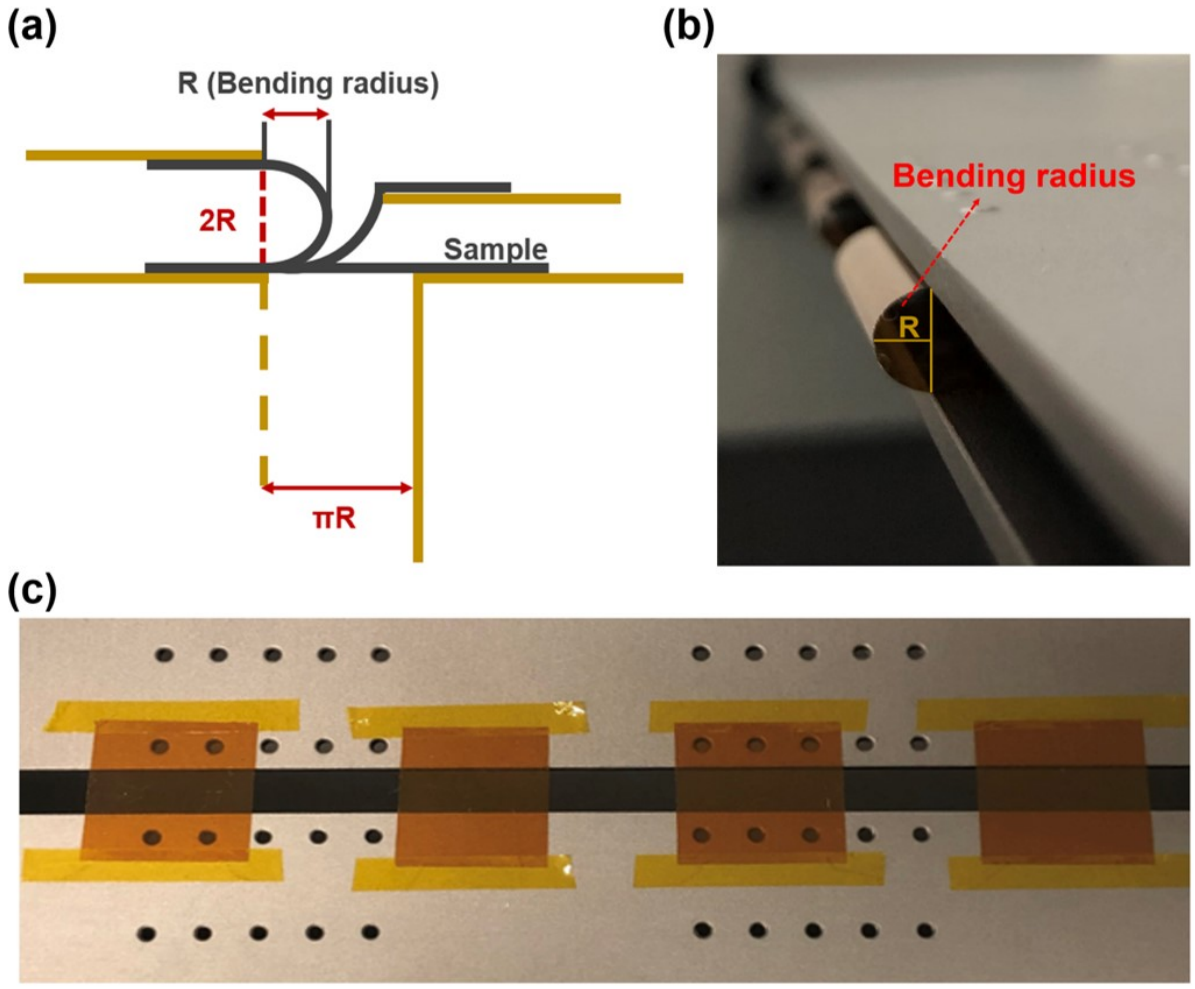

Fig. S5 (a) Schematic diagram of the bending equipment operation; (b-c) schematic diagram of sample bending 0° and 180°.

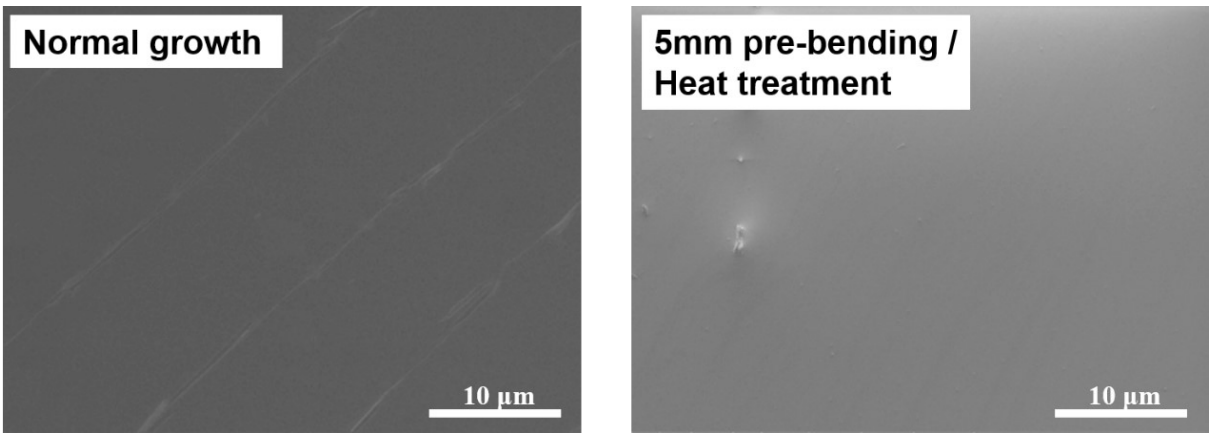

Fig. S6 The surface SEM image of ALD-Al_2O_3 deposited by normal growth and 5 mm pre-bending heat treatment process with 10,000 bending cycles at 3 mm bending radius

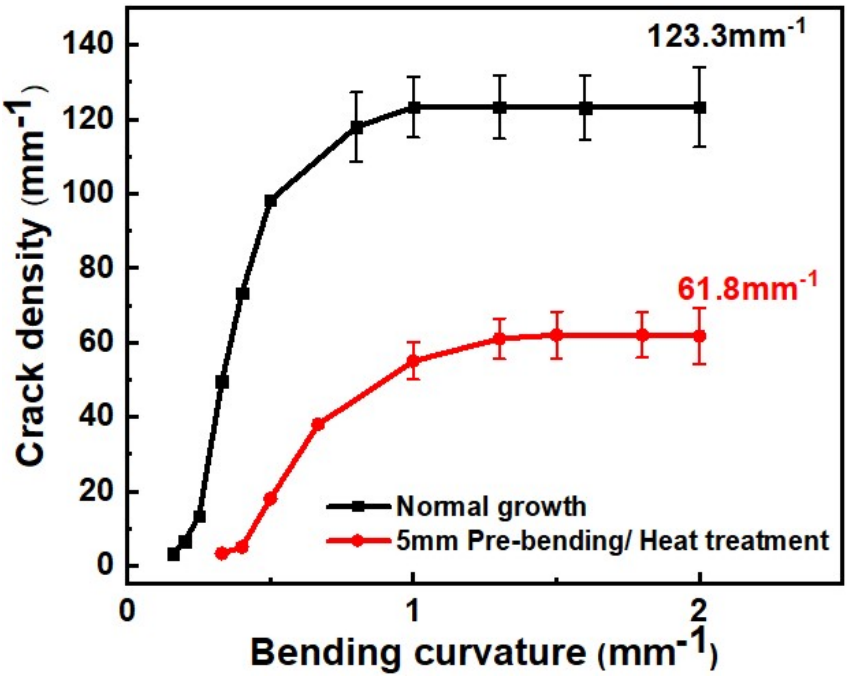

Fig. S7 Surface crack density curves of ALD-Al_2O_3 grown by normal growth and 5-mm pre-bending heat treatment processes after bending at different bending radii.

Table S4. Crack density data at six regions in the center of the bend with a smaller bending radius for ALD-Al_2O_3 deposited by the normal growth process.

Bending curvature	Crack density (mm^{-1})					
0.8	113.3	121.7	126.7	125	118.3	123.2
1	109.8	113.2	123.3	128.8	123.2	130.5
1.3	123.4	129.1	124.3	124.3	118.6	119.5
1.6	127.7	123.7	123.1	118.2	114.8	112.3
2	129.8	114.2	116.5	129.8	123.2	126.5

Table S5. Crack density data at six regions in the center of the bend with a smaller bending radius for ALD-Al_2O_3 deposited by 5-mm pre-bending heat treatment process.

Bending curvature	Crack density (mm^{-1})					
1	59.6	52.3	55.2	63.2	63.3	61.6
1.3	57.8	56.1	53.1	69.4	50.1	51.7
1.5	66.63	59.96	56.62	69.95	63.28	56.61
1.8	65.4	55.1	58.5	60.1	59.3	61.3
2	69.9	56.6	59.9	53.2	66.6	59.9

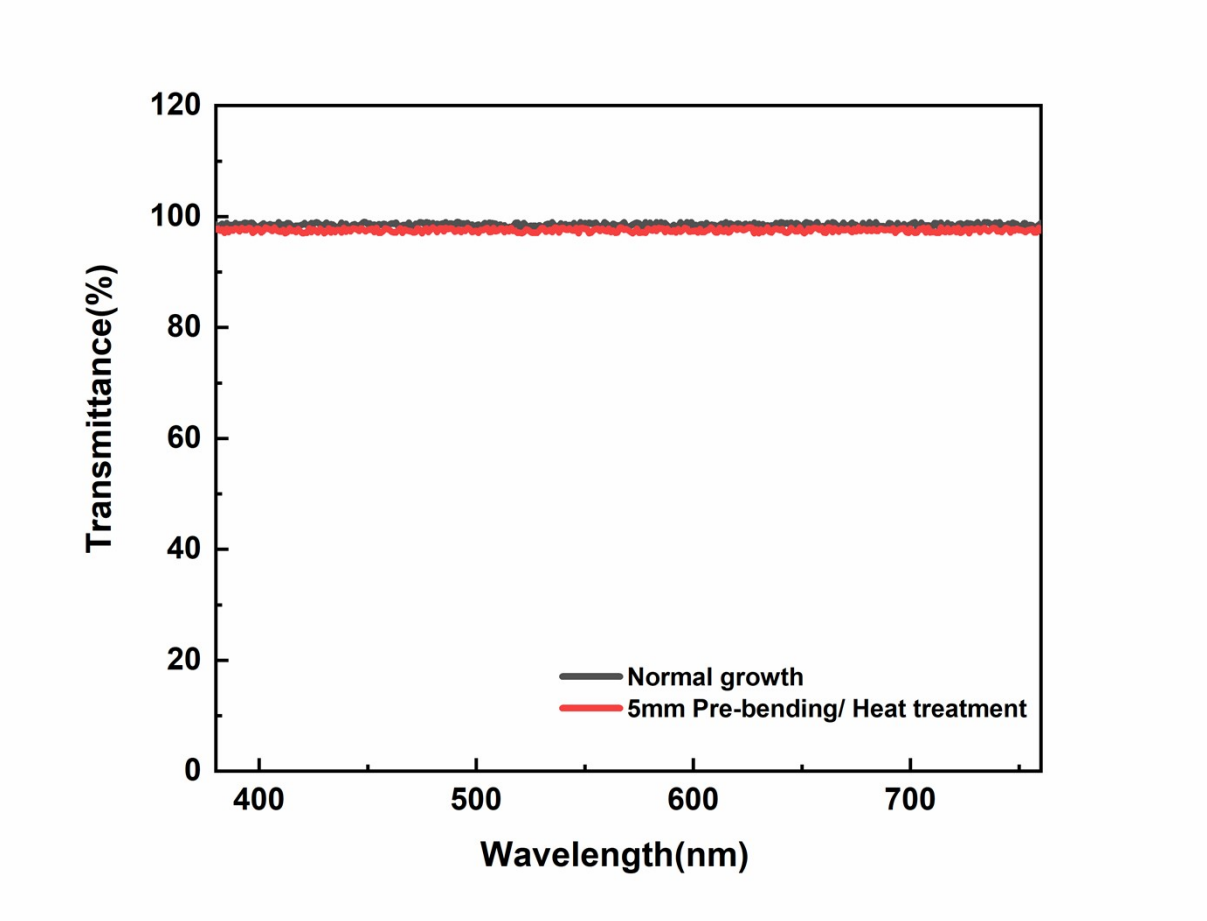

Fig. S8 The optical transmittance of ALD-Al_2O_3 films prepared by normal growth and 5-mm pre-bending heat treatment processes.