

```

In[1]:= Print[];
Print["Metamaterial(SemiconductorsV52p1886).nb"];

Print[" -----"];
Print[" The Image of the Metamaterial of the paper "];
Print[" Model of Metamaterial Based on Graphene Scrolls "];
Print[" and Carbon Nanotubes with Negative Refractive Index "];
Print[" / A.I. Siahlo, N.A. Poklonski, S.A. Vyrko and S.V. Ratkevich "];
Print[" //Semiconductors.- 2018.- V. 52, „ 14.- P.1886 (4 pp.)."];
Print[" [DOI: 10.1134/S1063782618140294] "];
Print[" -----"];

Print[" I.1. The Input Parameters -----"];
NumberScrollLayersp1 = 1; NumberScrollLayersp2 = 2;
NumberScrollLayersp = NumberScrollLayersp2;
Print["NumberScrollLayers=", NumberScrollLayersp];
n10 = 10; nNanotubep = n10;
Print["nNanotube=", nNanotubep];
nNanotubes2 = 2; nNanotubes3 = 3; nNanotubes4 = 4;
nScrolls2 = 2; nScrolls3 = 3; nScrolls3l = 3; nScrolls4 = 4;
nNanoscrollsXp = nScrolls3;
nNanoscrollsZp = nScrolls2;
nNanotubesYp = nNanotubes3;
nNanotubesZp = nNanotubes3;
Print["Along X-direction: nNanoscrollsX=", nNanoscrollsXp,
      ", Along Z-direction: nNanoscrollsZ=", nNanoscrollsZp];
Print["Along Y-direction: nNanotubesY=", nNanotubesYp,
      ", Along Z-direction: nNanotubesZ=", nNanotubesZp];
PhiRotPid2 = Pi / 2;
L12d7nm = 12.709 nm;
RIn1d1nm = 1.1 nm;
L15nm = 15. nm; L1p = L15nm;
L1p = L15nm;
L1p = L12d7nm;
Spirale1RotAnglep = 0;
Spirale2RotAnglep = Pi;
NanoribbonLengthp = L1p;
Print[" The length of a carbon nanoribbons L1=", L1p / nm, "nm"];
RIn1p = RIn1d1nm;
Print["The Inner radius of nanoscrolls RIn1=", RIn1p / nm, "nm"];
Lw1nm = 1 nm; Lw12nm = 12. nm;
Lw12nm = 12 nm; Lw60nm = 60 nm; Lw5nm = 5 nm;
Lwp = Lw5nm;
NanoscrollWidth = Lwp;
NanoribbonWidth = Lwp;
Print[" The carbon nanoscroll width w=", Lwp / nm, "nm"];
ShiftX0nm = 0 nm; ShiftY0nm = 0 nm;
Print[" I.5.The parameters for the visualisation"];
Nu10 = 40; Scale09 = 0.99;
ShowScrollSpirales = True;
ShowNanoscrollSingle = True;
ShowStructureProjections = True;
Print[" -----End Of The Input-----"];

Print[" -----"];
ThisNotebookFileName = NotebookInformation[][1, 2, 2];
Print["ThisNotebookFileName = ", ThisNotebookFileName];

```

```

StructureNameNanoscrollsXZ =
    StringJoin["NanocrollsX", ToString[nNanoscrollsXp], "Z", ToString[nNanoscrollsZp]];
StructureNameNanotubesYZ = StringJoin["NanotubesY",
    ToString[nNanotubesYp], "Z", ToString[nNanotubesZp]];
StructureName = StringJoin["Metamaterial", StructureNameNanoscrollsXZ,
    StructureNameNanotubesYZ];
Print["StructureName=", StructureName];
Print["I.0.1 The Units (nm, meV, AA)"];
"nm=10^(-9)m;";
nm = 10^(-9) m;
AA = 10^(-10) m;
JJkgms = kg m^2 / s^2;
Farad = Amper^2 s^4 kg^(-1) m^(-2);
Cl = Amper s;
Volt = m^2 kg / s^3 / Amper;
"eV=JJ Electronp;";
JJ = eV / Electron;
meV = N[eV / 1000];
Print["I.0.2. The physical constants"];
Print[" The interatomic distance aCC and the interlayer distance h"];
aCC142AA = 1.42 AA; aCCp = aCC142AA;
NatomsInCell2 = 2; NatomsInCellp = NatomsInCell2;
Print["NatomsInCell=", NatomsInCellp];
h335nm = 0.3354 nm; hp = h335nm;
Print["aCC=", aCCp / nm, "nm, h=", hp / nm, " nm"];
Print["I.0.3. The functions that will be used"];
frNanotubenn[n_, aCC_] := n^3 aCC / (2 Pi);
fSpiraleLen[NumberScrollLayersv_, PhiInv_, PhiOutv_, hv_] :=
(1 / (4 Pi) hv NumberScrollLayersv (-PhiInv Sqrt[1 + PhiInv^2] +
    PhiOutv Sqrt[1 + PhiOutv^2] - ArcSinh[PhiInv] +
    ArcSinh[PhiOutv]));
Print["fSpiraleLen[NumberScrollLayersv,PhiInv, PhiOutv, hv]=",
    fSpiraleLen[NumberScrollLayersv, PhiInv, PhiOutv, hv]];
fPhiOutvsPhiInLh[NumberScrollLayersv_, PhiInv_, Lv_, hv_] :=
Sqrt[4 Pi Lv / (NumberScrollLayersvhv) + PhiInv^2];
Print["fPhiOutvsPhiInLh[NumberScrollLayersv,PhiInv, Lv, hv]=",
    fPhiOutvsPhiInLh[NumberScrollLayersv, PhiInv, Lv, hv]];
fPhivsRh[NumberScrollLayersv_, Rv_, hv_] := Rv^2 Pi / (NumberScrollLayersvhv);
Print["fPhivsRh[NumberScrollLayersv, Rv, hv]=", fPhivsRh[NumberScrollLayersv, Rv, hv]];
fRvsPhih[NumberScrollLayersv_, Phiv_, hv_] := (NumberScrollLayersvhv) Phiv / (2 Pi);
Print["fRvsPhih[NumberScrollLayersv,Phiv,hv]=",
    fRvsPhih[NumberScrollLayersv, Phiv, hv]];
fPhiOut1vsL1RIn1h[NumberScrollLayersv_, L1v_, RIn1v_, hv_] :=
fPhiOutvsPhiInLh[NumberScrollLayersv,
    fPhivsRh[NumberScrollLayersv, RIn1v, hv], L1v, hv];
Print["fPhiOut1vsL1RIn1h[NumberScrollLayersv, L1v, RIn1v, hv]=",
    fPhiOut1vsL1RIn1h[NumberScrollLayersv, L1v, RIn1v, hv]];
fPhiIn2[NumberScrollLayersv_, RIn1v_, hv_, dPhi12v_] :=
fPhivsRh[NumberScrollLayersv, RIn1v, hv] + dPhi12v;
Print["fPhiIn2[NumberScrollLayersv, RIn1v, hv, dPhi12v]=",
    fPhiIn2[NumberScrollLayersv, RIn1v, hv, dPhi12v]];
fPhiOut2[NumberScrollLayersv_, L1v_, RIn1v_, hv_, dPhi12v_] :=
fPhiOutvsPhiInLh[NumberScrollLayersv,
    fPhiIn2[NumberScrollLayersv, RIn1v, hv, dPhi12v], L1v, hv];
rNanotubep = frNanotubenn[n10, aCCp];
rNanotubep = rNanotubep;
Print["rNanotube(", n, ", " n, ")=", rNanotubep / nm, "nm"];

```

```

PhiIn1p = fPhivsRh[NumberScrollLayersp, RIn1p, hp];
PhiOut1p = fPhiOut1vsL1RIn1h[NumberScrollLayersp, L1p, RIn1p, hp];
Print["PhiIn1=", PhiIn1p / (2 Pi), "(2Pi), PhiOut1=", PhiOut1p / (2 Pi), "(2Pi)"];
PhiIn2p = PhiIn1p + Pi;
PhiOut2p = PhiOut1p + Pi;
Print["PhiIn2=", PhiIn2p / (2 Pi), "(2Pi), PhiOut2=", PhiOut2p / (2 Pi), "(2Pi)"];
ROut1p = fRvsPhih[NumberScrollLayersp, PhiOut1p, hp];
Print["RIn1=", RIn1p / nm, "nm, ROut1=", ROut1p / nm, "nm"];
aScrollXZp = 2 ROut1p + hp + 2 rNanotubep;
Print[
  " The distance between the centurms of the NanoScrolls in the XZ-plane aScrollXZ=",
  aScrollXZp / nm, "nm"];
aNanotubesXyp = 2 ROut1p + hp + 2 rNanotubep;
Print[
  " The distance between the centurms of the Nanotubes in the XY-plane aNanotubesXY=",
  aNanotubesXyp / nm, "nm"];
NanotubeLengthXp = aScrollXZp (nNanoscrollsXp + 1);
Print["The Length of the Nanotubes along the X-axis: NanotubeLengthX=",
  NanotubeLengthXp / nm, "nm"];
NanoscrollLengthYp = aNanotubesXyp (nNanotubesZp);
Print["The Length of the Nanoscrolls along the Y-axis: NanoscrollLengthY=",
  NanoscrollLengthYp / nm, "nm"];
StructureLengthZp = nNanotubesZp aScrollXZp;
Print["The Length of the Structure along the Z-axis: StructureLengthZ=",
  StructureLengthZp / nm, "nm"];

nm = 1.; m = 10^9 nm;

Print["Draw the spirales of a nanoscroll"];
Spirale1ScrollSingle = ParametricPlot[
  {Cos[Phiv] (Phiv - Spirale1RotAnglep) (NumberScrollLayersphp) / (2 Pi) / nm Scale09,
   Sin[Phiv] (Phiv - Spirale1RotAnglep) (NumberScrollLayersphp) / (2 Pi) / nm Scale09},
  {Phiv, Spirale1RotAnglep + PhiIn1p, Spirale1RotAnglep + PhiOut1p},
  PlotRange -> {{-ROut1p / nm, ROut1p / nm}, {-ROut1p / nm, ROut1p / nm}},
  PlotStyle -> {Black, Thick}, Axes -> True];

If[NumberScrollLayersp == 1,
  If[ShowScrollSpirales,
    Print["Show[Spirale1ScrollSingle]:"];
    Print[Show[Spirale1ScrollSingle]];
  ];
];

Spirale2ScrollSingle = ParametricPlot[
  {Cos[Phiv] (Phiv - Spirale2RotAnglep) (NumberScrollLayersphp) / (2 Pi) / nm Scale09,
   Sin[Phiv] (Phiv - Spirale2RotAnglep) (NumberScrollLayersphp) / (2 Pi) / nm Scale09},
  {Phiv, Spirale2RotAnglep + PhiIn2p - Pi, Spirale2RotAnglep + PhiOut2p - Pi},
  PlotRange -> {{-ROut1p / nm, ROut1p / nm}, {-ROut1p / nm, ROut1p / nm}},
  PlotStyle -> {Gray, Thick}, Axes -> True];

If[NumberScrollLayersp == 2,
  If[ShowScrollSpirales,
    Print["Show[{Spirale1ScrollSingle,Spirale2ScrollSingle}]:"];
    Print[Show[{Spirale1ScrollSingle, Spirale2ScrollSingle}]];
  ];
];

Print[];
Print["Draw the spirales of the nanoscrolls of the structure:"];
Print["aScrollXZp=", aScrollXZp / nm, "nm"];
Print["aScrollXZp=2ROut1p+hp+2rNanotubep, {2ROut1p, hp, 2rNanotubep}=",

```

```

{2 ROut1p, hp, 2 rNanotubep}}];
tSpirale1Scroll = Table[ParametricPlot[
  {aScrollXZp (iScrollX - nNanoscrollsXp) + Cos[Phiv] (Phiv - Spirale1RotAnglep)
    (NumberScrollLayersphp) / (2 Pi) Scale09, aScrollXZp (jScrollY - nNanoscrollsZp) +
    Sin[Phiv] (Phiv - Spirale1RotAnglep) (NumberScrollLayersphp) / (2 Pi) Scale09},
  {Phiv, Spirale1RotAnglep + PhiIn1p, Spirale1RotAnglep + PhiOut1p},
  PlotRange -> {{-(nNanoscrollsXp - 1) aScrollXZp - 1 ROut1p, ROut1p},
    {-(nNanoscrollsZp - 1) aScrollXZp - 1 ROut1p, ROut1p}}, PlotStyle -> {Black, Thick},
  Axes -> True], {iScrollX, 1, nNanoscrollsXp}, {jScrollY, 1, nNanoscrollsZp}];
If[ShowScrollSpirales,
Print["Show[tSpirale1Scroll]:"];
Print[Show[tSpirale1Scroll, ImageSize -> Large]];
];
tSpirale2Scroll = Table[ParametricPlot[
  {aScrollXZp (iScrollX - nNanoscrollsXp) + Cos[Phiv] (Phiv - Spirale2RotAnglep)
    (NumberScrollLayersphp) / (2 Pi) Scale09, aScrollXZp (jScrollY - nNanoscrollsZp) +
    Sin[Phiv] (Phiv - Spirale2RotAnglep) (NumberScrollLayersphp) / (2 Pi) Scale09},
  {Phiv, Spirale2RotAnglep + PhiIn2p - Pi, Spirale2RotAnglep + PhiOut2p - Pi},
  PlotRange -> {{-(nNanoscrollsXp - 1) aScrollXZp - 1 ROut1p, ROut1p},
    {-(nNanoscrollsZp - 1) aScrollXZp - 1 ROut1p, ROut1p}}, PlotStyle -> {Gray, Thick},
  Axes -> True], {iScrollX, 1, nNanoscrollsXp}, {jScrollY, 1, nNanoscrollsZp}];
If[ShowScrollSpirales,
If[NumberScrollLayerssp == 1,
Print["Show[tSpirale1Scroll]:"]; Print[Show[tSpirale1Scroll, ImageSize -> Large]];
];
If[NumberScrollLayerssp == 2,
Print["Show[tSpirale1Scroll,tSpirale2Scroll]:"];
Print[Show[tSpirale1Scroll, tSpirale2Scroll, ImageSize -> Large]];
];
];
Print["Draw the Nanotubes of the structure:"];
nm = 1; m = 10^9 nm; N07 = 0.7;
tNanotubeYZ =
Table[ParametricPlot3D[{xv, jNanotubeY aScrollXZp - aScrollXZp 0.5 + Cos[Phiv] rNanotubep,
  (kNanotubeZ - 1) aScrollXZp + Sin[Phiv] rNanotubep},
  {Phiv, Spirale1RotAnglep + PhiIn1p, Spirale1RotAnglep + PhiOut1p},
  {xv, aScrollXZp 0.45, NanotubeLengthXp - aScrollXZp 0.55},
  PlotPoints -> 5, PlotStyle -> {Gray, Thick},
  PlotRange -> {{-aScrollXZp N07, NanotubeLengthXp + aScrollXZp N07},
    {-aNanotubesXYp N07, NanoscrollLengthYp + aNanotubesXYp N07},
    {-aScrollXZp N07, (nNanoscrollsZp) aScrollXZp + aScrollXZp N07}}, (*Axes->None,*)
  ColorFunction -> Function[{x, y, z, u, v}, Gray], ColorFunctionScaling -> False],
  {jNanotubeY, 1, nNanotubesYp}, {kNanotubeZ, 1, nNanotubesZp}];
(*Print["The tNanotubeYZ:"];
Print[Show[tNanotubeYZ, ViewPoint -> Front]]];*)
nm = 1.; m = 10^9 nm; N01 = 0.01;
Print["Define all 3D-scrolls"];
Scroll113D00 =
ParametricPlot3D[{Cos[Phiv] (Phiv - Spirale1RotAnglep) NumberScrollLayersphp / (2 Pi),
  yv, Sin[Phiv] (Phiv - Spirale1RotAnglep) NumberScrollLayersphp / (2 Pi)},
  {Phiv, Spirale1RotAnglep + PhiIn1p, Spirale1RotAnglep + PhiOut1p},
  {yv, 0, NanoscrollLengthYp}, PlotPoints -> 5,
  PlotStyle -> {Gray, Thick}, PlotRange -> {{-ROut1p/nm, ROut1p/nm},
    {-aScrollXZp N07, NanoscrollLengthYp/nm}, {-ROut1p/nm, ROut1p/nm}}, Axes -> True,
  ColorFunction -> Function[{x, y, z, u, v}, Gray], ColorFunctionScaling -> False];
Scroll123D00 = ParametricPlot3D[{Cos[Phiv] (Phiv - Spirale2RotAnglep) NumberScrollLayerssp
  hp / (2 Pi), yv, Sin[Phiv] (Phiv - Spirale2RotAnglep) NumberScrollLayersphp / (2 Pi)},

```

```

{Phiv, Spirale2RotAnglep+PhiIn2p-Pi, Spirale2RotAnglep+PhiOut2p-Pi},
{yv, 0, NanoscrollLengthYp}, PlotPoints -> 5,
PlotStyle -> {Gray, Thick}, PlotRange -> {{-ROut1p/nm, ROut1p/nm},
{-aScrollXZpN07, NanoscrollLengthYp/nm}, {-ROut1p/nm, ROut1p/nm}}, Axes -> True,
ColorFunction -> Function[{x, y, z, u, v}, LightGray], ColorFunctionScaling -> False];
If[NumberScrollLayersp == 1,
If[ShowNanoscrollSingle,
Print["Show[Scroll13D00]:"];
Print[Show[Scroll13D00, ImageSize -> Small]];
];
];
If[NumberScrollLayersp == 2,
If[ShowNanoscrollSingle,
Print["Show[Scroll13D00],
Show[Scroll23D00], Show[Scroll13D00, Scroll23D00]:"];
Print[Show[Scroll13D00, ImageSize -> Small], Show[Scroll23D00, ImageSize -> Small],
"
", Show[Scroll13D00, Scroll23D00, ImageSize -> Small]];
];
];

Print["Define tScroll13DXZ and tScroll23DXZ"];
tScroll13DXZ = Table[ParametricPlot3D[
{iNanoscrollX aScrollXZp/nm + Cos[Phiv] (Phiv - Spirale1RotAnglep) NumberScrollLayersp
hp/nm/(2 Pi), yv, -aScrollXZp/nm/2 + kNanoscrollZ aScrollXZp/nm +
Sin[Phiv] (Phiv - Spirale1RotAnglep) NumberScrollLayersp hp/nm/(2 Pi)},
{Phiv, Spirale1RotAnglep+PhiIn1p, Spirale1RotAnglep+PhiOut1p},
{yv, 0, NanoscrollLengthYp}, PlotPoints -> 5, PlotStyle -> {Gray, Thick},
PlotRange -> {{-aScrollXZpN07, NanotubeLengthXp+aScrollXZpN07},
{-aNanotubesXYpN07, NanoscrollLengthYp+aNanotubesXYpN07},
{-aScrollXZpN07, (nNanoscrollsZp) aScrollXZp+aScrollXZpN07}}, Axes -> True,
ColorFunction -> Function[{x, y, z, u, v}, Gray], ColorFunctionScaling -> False],
{iNanoscrollX, 1, nNanoscrollsXp}, {kNanoscrollZ, 1, nNanoscrollsZp}];
tScroll23DXZ = Table[ParametricPlot3D[{iNanoscrollX aScrollXZp/nm +
Cos[Phiv] (Phiv - Spirale2RotAnglep) NumberScrollLayersp hp/nm/(2 Pi),
yv, -aScrollXZp/nm/2 + kNanoscrollZ aScrollXZp/nm +
Sin[Phiv] (Phiv - Spirale2RotAnglep) NumberScrollLayersp hp/nm/(2 Pi)},
{Phiv, Spirale2RotAnglep+PhiIn2p-Pi, Spirale2RotAnglep+PhiOut2p-Pi},
{yv, 0, NanoscrollLengthYp}, PlotPoints -> 5, PlotStyle -> {Gray, Thick},
PlotRange -> {{-aScrollXZpN07, NanotubeLengthXp+aScrollXZpN07},
{-aNanotubesXYpN07, NanoscrollLengthYp+aNanotubesXYpN07},
{-aScrollXZpN07, (nNanoscrollsZp) aScrollXZp+aScrollXZpN07}}, Axes -> True,
ColorFunction -> Function[{x, y, z, u, v}, LightGray], ColorFunctionScaling -> False],
{iNanoscrollX, 1, nNanoscrollsXp}, {kNanoscrollZ, 1, nNanoscrollsZp}];
(*Print["Show[tScroll13DXZ,tScroll23DXZ]:"];
Print[Show[tScroll13DXZ,tScroll23DXZ,ImageSize->Medium]]];*)
Print[" -----Show the Metamaterial:-----"];
Print[" (Fig.4 of the paper)];
Print[" Model of Metamaterial Based on Graphene Scrolls "];
Print[" and Carbon Nanotubes with Negative Refractive Index "];
Print[" / A.I. Siahlo, N.A. Poklonski, S.A. Vyrko and S.V. Ratkevich "];
Print[" //Semiconductors.- 2018.- V. 52, „ 14.- P.1886 (4 pp.). ) "];
Print[Show[tScroll13DXZ, tScroll23DXZ, tNanotubeYZ, ImageSize -> Medium,
ViewPoint -> {StructureLengthZp1000, StructureLengthZp1000
, StructureLengthZp1000}]];
If[ShowStructureProjections,
Print[" and its projections:"];
Print[

```

```

Show[tScroll113DXZ, tScroll123DXZ, tNanotubeYZ, ImageSize -> Medium, ViewPoint -> Front],
Show[tScroll113DXZ, tScroll123DXZ, tNanotubeYZ, ImageSize -> Medium, ViewPoint -> Left]];
Print[Show[tScroll113DXZ, tScroll123DXZ, tNanotubeYZ, ImageSize -> Medium, ViewPoint -> Top]];
];
Print["The parameters of the metamaterial"];
Print["      {nNanoscrollsXp,nNanotubesYp,nNanoscrollsZp,nNanotubesZp}:"];
Print["      ", {nNanoscrollsXp, nNanotubesYp, nNanoscrollsZp, nNanotubesZp}];
StructureFigure = Show[tScroll113DXZ, tScroll123DXZ, tNanotubeYZ,
  ImageSize -> Medium, ViewPoint -> {StructureLengthZp1000, StructureLengthZp1000
, StructureLengthZp1000}];
StructureFigureFileName =
  ToFileName[NotebookDirectory[], StringJoin[StructureName, ".jpg"]];
Print["StructureFigureFileName=", StructureFigureFileName];
Export[StructureFigureFileName, StructureFigure];

```

Metamaterial(SemiconductorsV52p1886).nb

```

-----

The Image of the Metamaterial of the paper
Model of Metamaterial Based on Graphene Scrolls
and Carbon Nanotubes with Negative Refractive Index
/ A.I. Siahlo, N.A. Poklonski, S.A. Vyrko and S.V. Ratkevich
//Semiconductors.- 2018.- V. 52, „ 14.- P.1886 (4 pp.).
[DOI: 10.1134/S1063782618140294]
-----

I.1. The Input Parameters -----
NumberScrollLayers=2
nNanotube=10
Along X-direction: nNanoscrollsX=3, Along Z-direction: nNanoscrollsZ=2
Along Y-direction: nNanotubesY=3, Along Z-direction: nNanotubesZ=3
The length of a carbon nanoribbons L1=12.709nm
The Inner radius of nanoscrolls RIn1=1.1nm
The carbon nanoscroll width w=5nm
I.5.The parameters for the visualisation
-----End Of The Input-----
-----

ThisNotebookFileName = Metamaterial(SemiconductorsV52p1886).m
StructureName=MetamaterialNanocrollsX3Z2NanotubesY3Z3
I.0.1 The Units (nm, meV, AA)
I.0.2. The physical constants
The interatomic distance aCC and the interlayer distance h
NatomsInCell=2

```

aCC=0.142nm, h=0.3354 nm

I.0.3. The functions that will be used

$$fSpiraleLen[NumberScrollLayersv, \Phi_{Inv}, \Phi_{Outv}, hv] = \frac{1}{4\pi} hv \text{NumberScrollLayersv} \left(-\Phi_{Inv} \sqrt{1 + \Phi_{Inv}^2} + \Phi_{Outv} \sqrt{1 + \Phi_{Outv}^2} - \text{ArcSinh}[\Phi_{Inv}] + \text{ArcSinh}[\Phi_{Outv}] \right)$$

$$f\Phi_{Outv}vs\Phi_{InLh}[NumberScrollLayersv, \Phi_{Inv}, Lv, hv] = \sqrt{\Phi_{Inv}^2 + \frac{4Lv\pi}{hv \text{NumberScrollLayersv}}}$$

$$f\Phi_{ivsRh}[NumberScrollLayersv, Rv, hv] = \frac{2\pi Rv}{hv \text{NumberScrollLayersv}}$$

$$fRvs\Phi_{ih}[NumberScrollLayersv, \Phi_{iv}, hv] = \frac{hv \text{NumberScrollLayersv} \Phi_{iv}}{2\pi}$$

$$f\Phi_{Outlv}vsLlRInlv[NumberScrollLayersv, Ll, RInlv, hv] = \sqrt{\frac{4Llv\pi}{hv \text{NumberScrollLayersv}} + \frac{4\pi^2 RInlv^2}{hv^2 \text{NumberScrollLayersv}^2}}$$

$$f\Phi_{In2}[NumberScrollLayersv, RInlv, hv, d\Phi_{i2v}] = d\Phi_{i2v} + \frac{2\pi RInlv}{hv \text{NumberScrollLayersv}}$$

rNanotube(n, n)=0.678nm

$\Phi_{In1}=1.63983(2\pi)$, $\Phi_{Out1}=2.95292(2\pi)$

$\Phi_{In2}=2.13983(2\pi)$, $\Phi_{Out2}=3.45292(2\pi)$

RIn1=1.1nm, ROut1=1.98082nm

The distance between the centurms of the NanoScrolls in the XZ-plane aScrollXZ=5.65304nm

The distance between the centurms of the Nanotubes in the XY-plane aNanotubesXY=5.65304nm

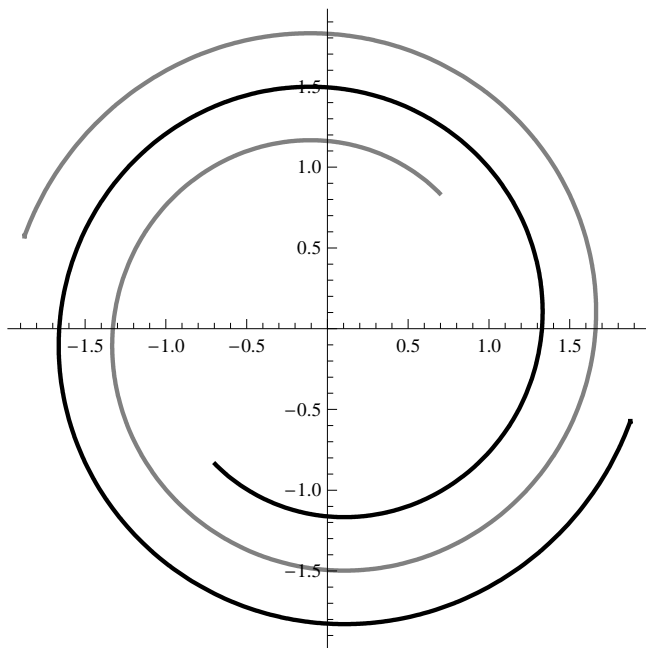
The Length of the Nanotubes along the X-axe: NanotubeLengthX=22.6122nm

The Length of the Nanoscrolls along the Y-axe: NanoscrollLengthY=16.9591nm

The Length of the Structure along the Z-axe: StructureLengthZ=16.9591nm

Draw the spirales of a nanoscroll

Show[{Spirale1ScrollSingle, Spirale2ScrollSingle}]:

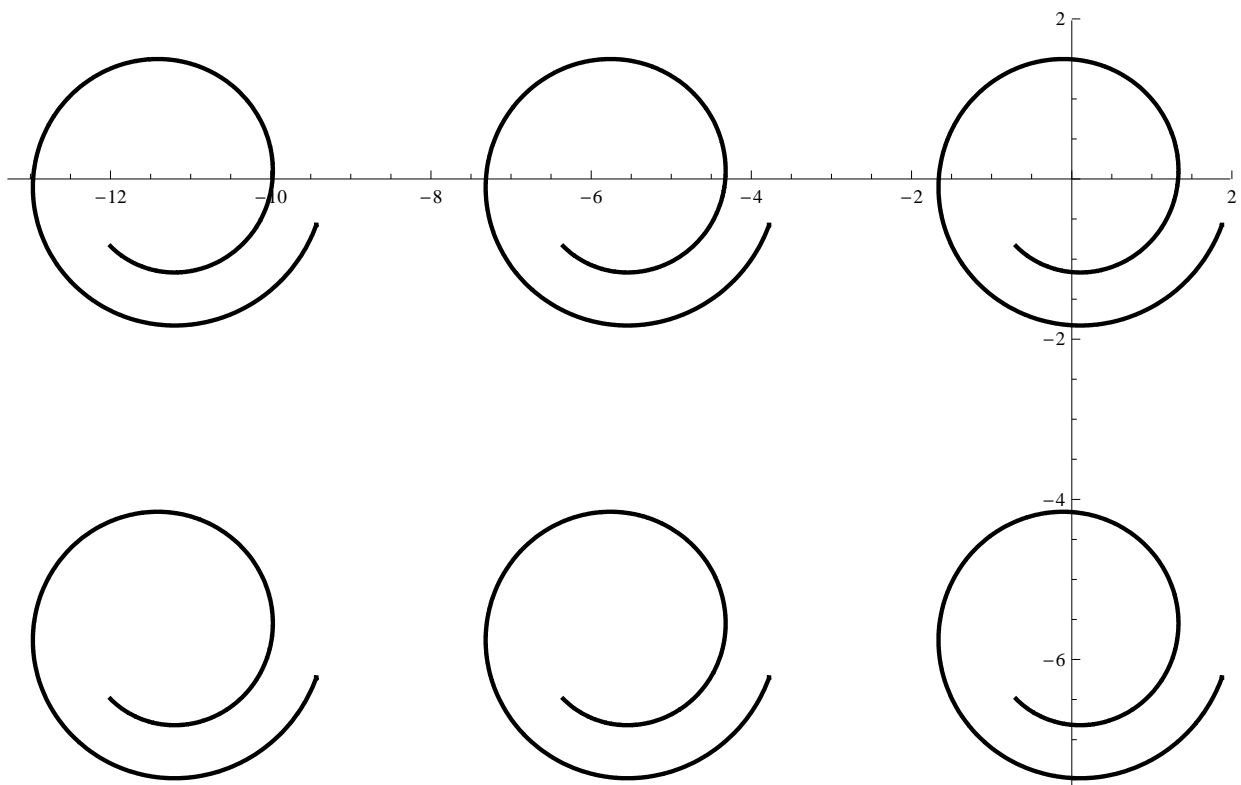


Draw the spirales of the nanoscrolls of the structure:

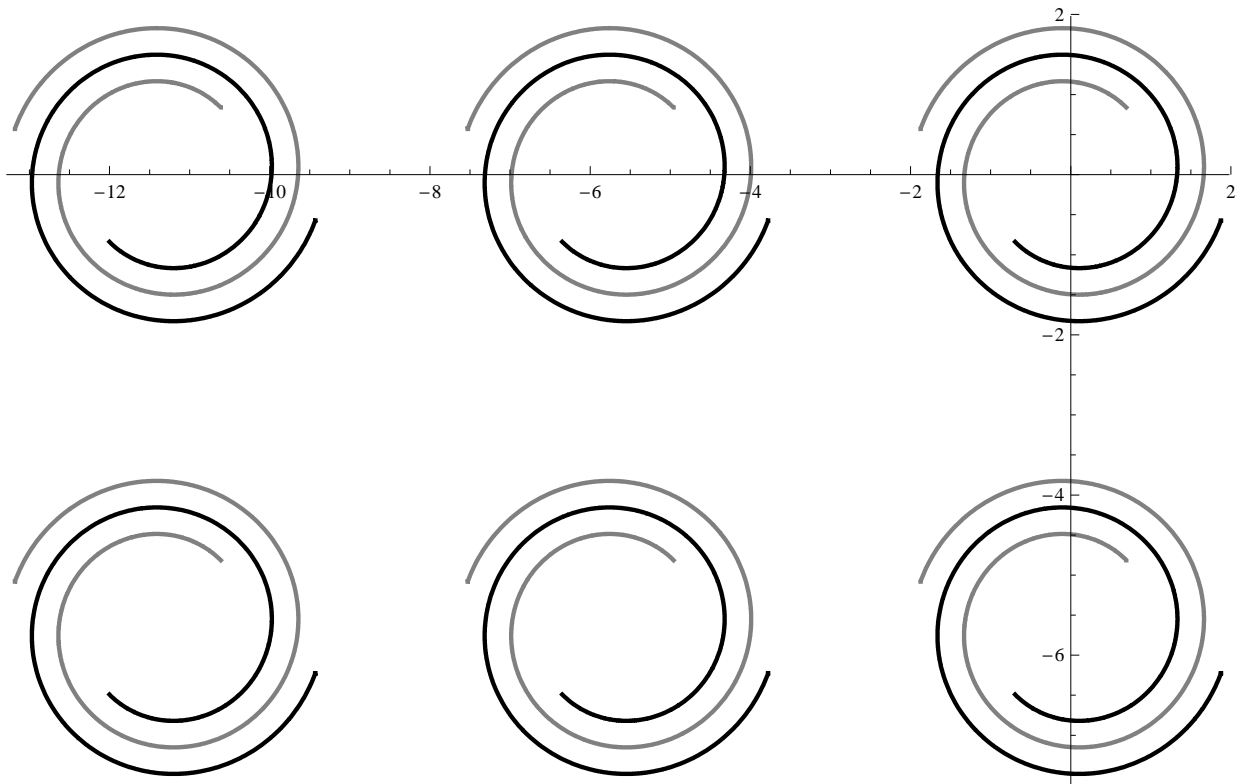
`aScrollXZp=5.65304nm`

`aScrollXZp=2ROutlp+hp+2rNanotubep, {2ROutlp, hp, 2rNanotubep}={3.96164, 0.3354, 1.356}`

`Show[tSpirale1Scroll]:`



`Show[tSpirale1Scroll,tSpirale2Scroll]:`

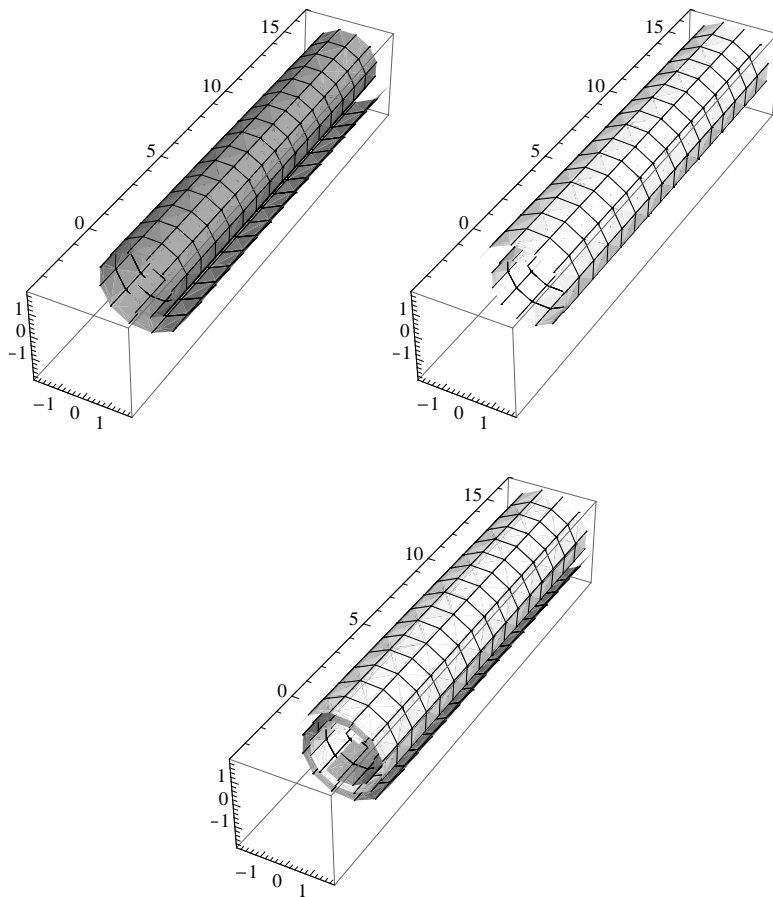


Draw the Nanotubes of the structure:

Define all 3D-scrolls

Show[Scroll113D00], Show[Scroll123D00],

Show[Scroll113D00,Scroll123D00]:



Define tScroll13DXZ and tScrol23DXZ

-----Show the Metamaterial:-----

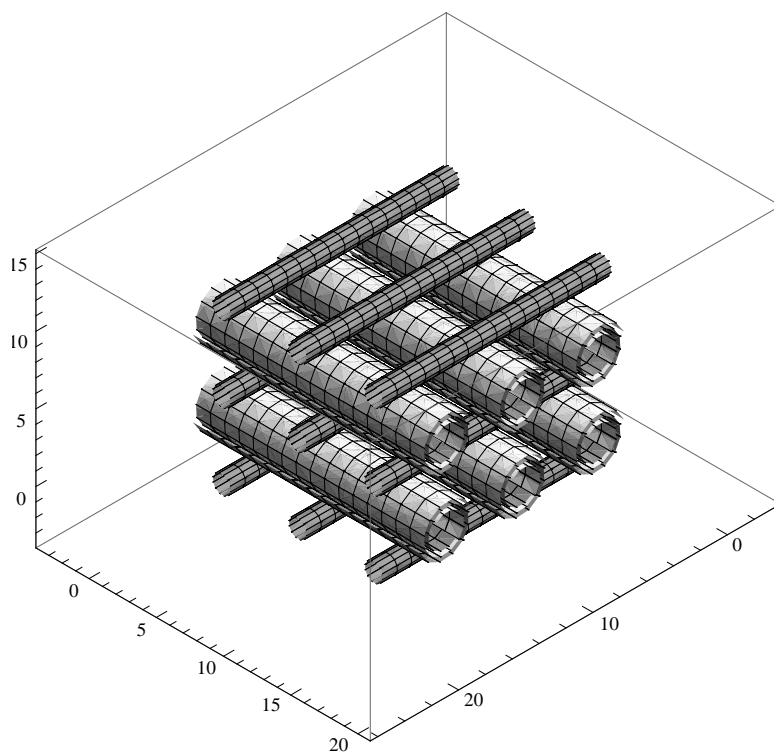
(Fig.4 of the paper

Model of Metamaterial Based on Graphene Scrolls

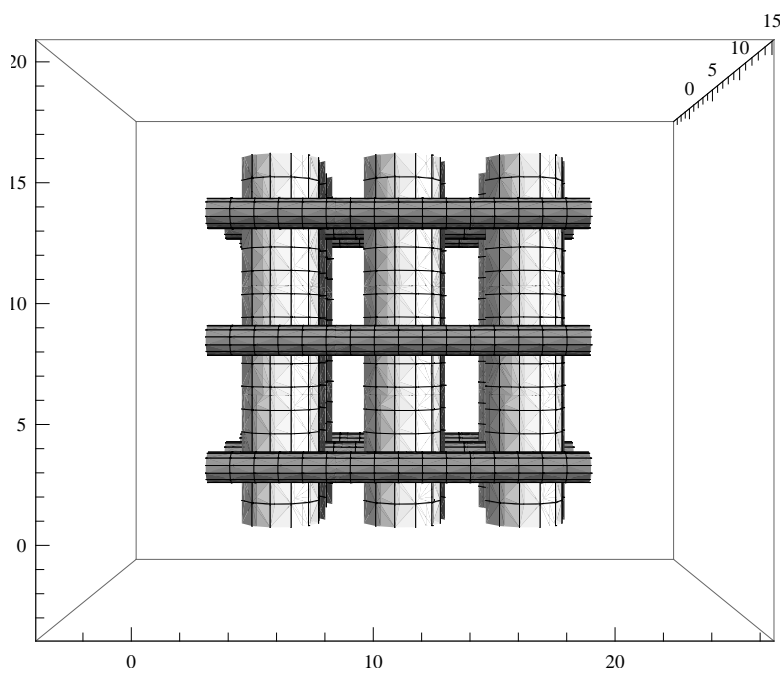
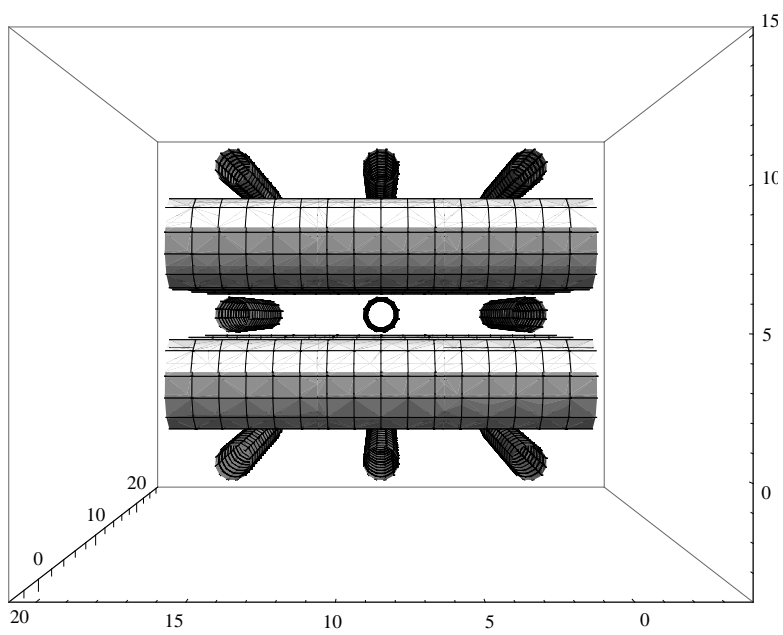
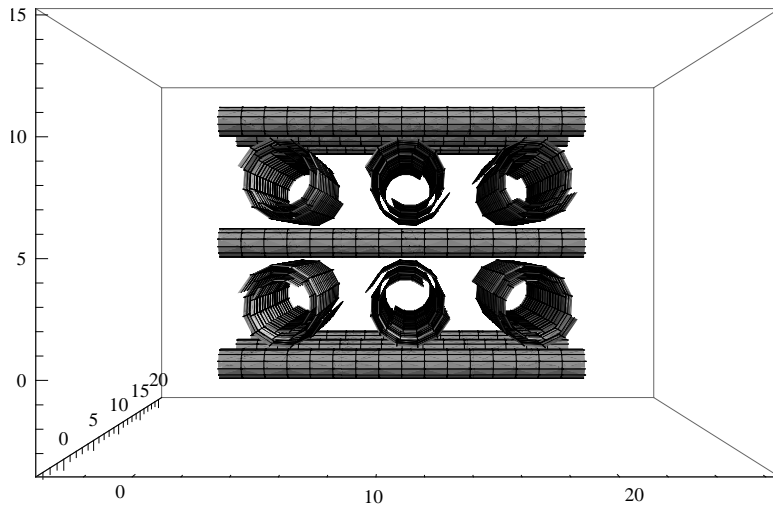
and Carbon Nanotubes with Negative Refractive Index

/ A.I. Siahlo, N.A. Poklonski, S.A. Vyrko and S.V. Ratkevich

//Semiconductors.- 2018.- V. 52, „ 14.- P.1886 (4 pp.).)



and its projections:



The parameters of the metamaterial

```
{nNanoscrollsXp,nNanotubesYp,nNanoscrollsZp,nNanotubesZp}:
```

```
{3, 3, 2, 3}
```

```
StructureFigureFileName=C:\1\MetamaterialNanocrollsX3Z2NanotubesY3Z3.jpg
```