DRDO SUMMER TRAINING 2018

INTERNSHIP REPORT

SUBMITTED TO :
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GROWTH OF HgCdTe EPILAYERS ON CdZnTe SUBSTRATE BY LIQUID PHASE EPITAXY TECHNIQUE

PREPARED BY
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ACKNOWLEDGEMENT

I take this opportunity to express my sincere gratitude towards Chanchal Sharma mam, who acted as mentor to me throughout this training period. Her theoretical approach to make me understand further applications proved fruitful and helped me to visualize the practical aspects of the laboratory process in a desirable and systematic manner. Without her constant motivation and underlying interest towards successful completion of my training, this report wouldn't have taken this present form.

I would also like to acknowledge the Liquid Phase Epitaxy Lab personnel whose keen involvement in the explanation of various laboratory growth techniques helped me get a feel of the process in a much appropriate way.

The amount of knowledge and experienced gained in this training period by working under this elite group of scientists cannot be expressed in words and will aide me tremendously in my future endeavours as a professional.

DEFENCE RESEARCH & DEVELOPMENT ORGANISATION

DRDO

The Defence Research and Development Organisation (DRDO) is an agency of the Republic of India, charged with the military's research and development, headquartered in New Delhi, India. It was formed in 1958 by the merger of the Technical Development Establishment and the Directorate of Technical Development and Production with the Defence Science Organisation. Initially, DRDO was a small organisation with 10 establishments or Laboratories. Over the years it has grown multi directionally in terms of subject, disciplines, number of laboratories as well as achievements and stature. Defence Research & Development Organisation (DRDO) works under Department of Defence Research and development of Ministry of Defence. DRDO dedicatedly working towards enhancing self-reliance in Defence systems and undertakes design & developments leading to production of world class weapon systems and equipment in accordance with the expressed needs and the qualitative requirements laid down by their services.
DRDO has a network of 52 laboratories, which are deeply engaged in developing defence technologies covering various fields, like aeronautics, armaments, electronics, land combat engineering, life sciences, materials, missiles, and naval systems,

DRDO is India's largest and most diverse research organisation. The organisation includes around 5,000 scientists belonging to the Defence Research & Development Service (DRDS) and about 25,000 other scientific, technical and supporting personnel.

SOLID STATE PHYSICS LABORATORY

SSPL

DESIGN & DEVELOPMET OF

- IR devices
- MEMS components
- SAW devices and sensors
- Ferrite components

Solid State Physics Laboratory (SSPL), one of the establishments under the Defence R&D Organisation (DRDO), Ministry of Defence was established in 1962 with the broad objective of developing an R&D base in the field of Solid State Materials, Devices and Sub-systems. The laboratory has a vision to be the centre of excellence in the development of solid states materials, devices and has a mission to develop and characterize high purity materials and solid state devices and to enhance infrastructure, technology for meeting the futuristic challenges. The major activities at SSPL include development of semi-conductor materials, solid state devices, electronic components/sub-systems and investigation of solid state materials/ devices.

AN OVERVIEW

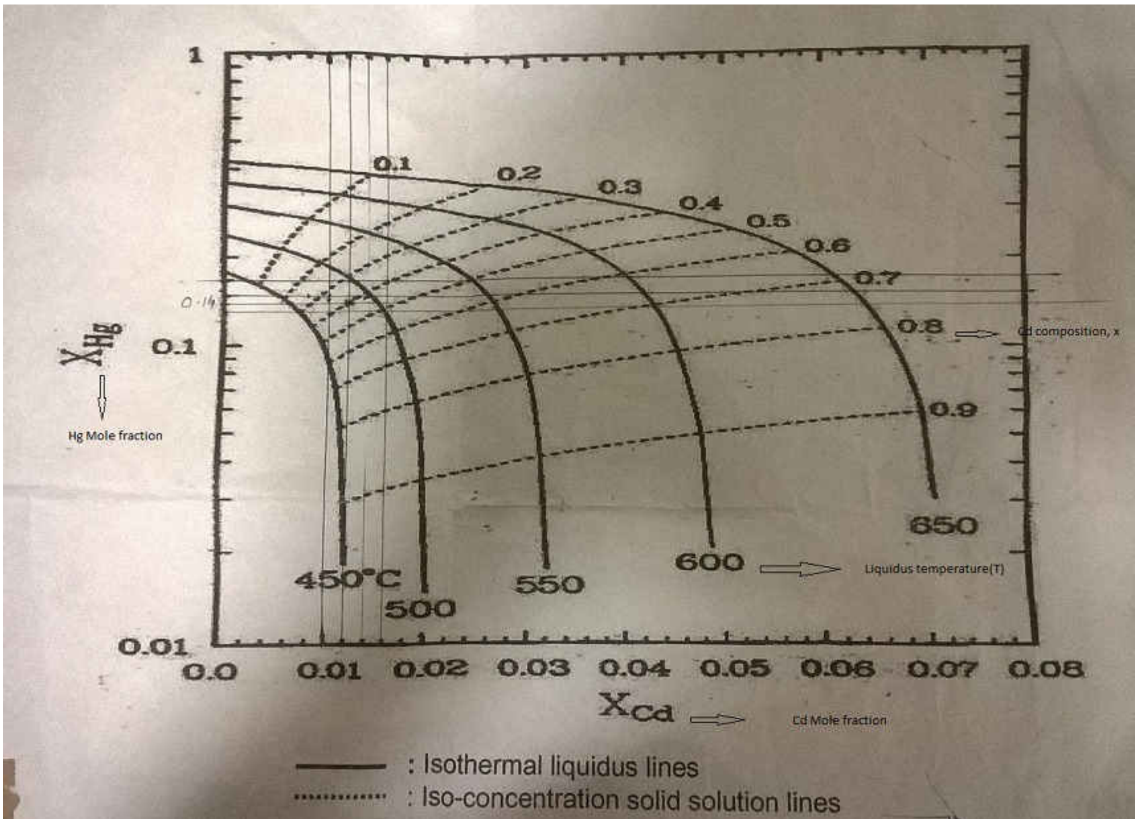
WEB APPLICATION DEVELOPED FOR SSPL, DRDO.

You can find the web application here:

https://anmolgoel.pythonanywhere.com

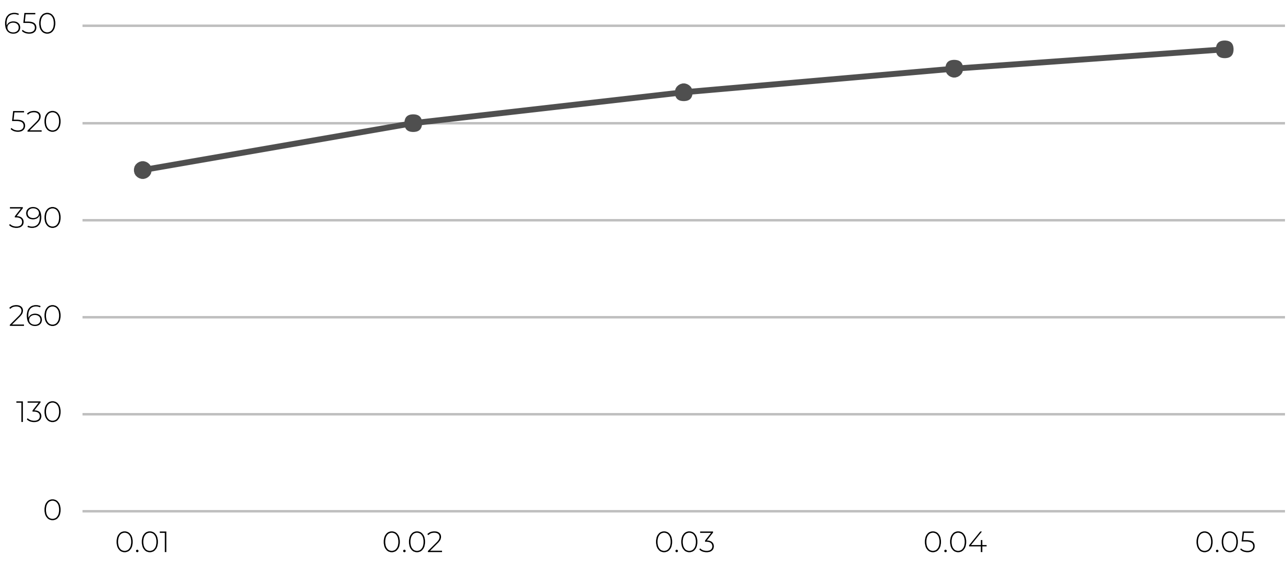
Documentation and Project Page :

https://www.agoel00.github.com/MCT



PYTHON + HTML/CSS/JAVASCRIPT

PROJECT OVERVIEW



Graph between Temperature and Cadmium mole fraction

WORKING DISCUSSION

VARIABLES

Hg and Cd are independent variables; T and X are dependent variables.

MERCURY

Hg mole fraction is in logarithmic scale.
Range: 0.1-0.9

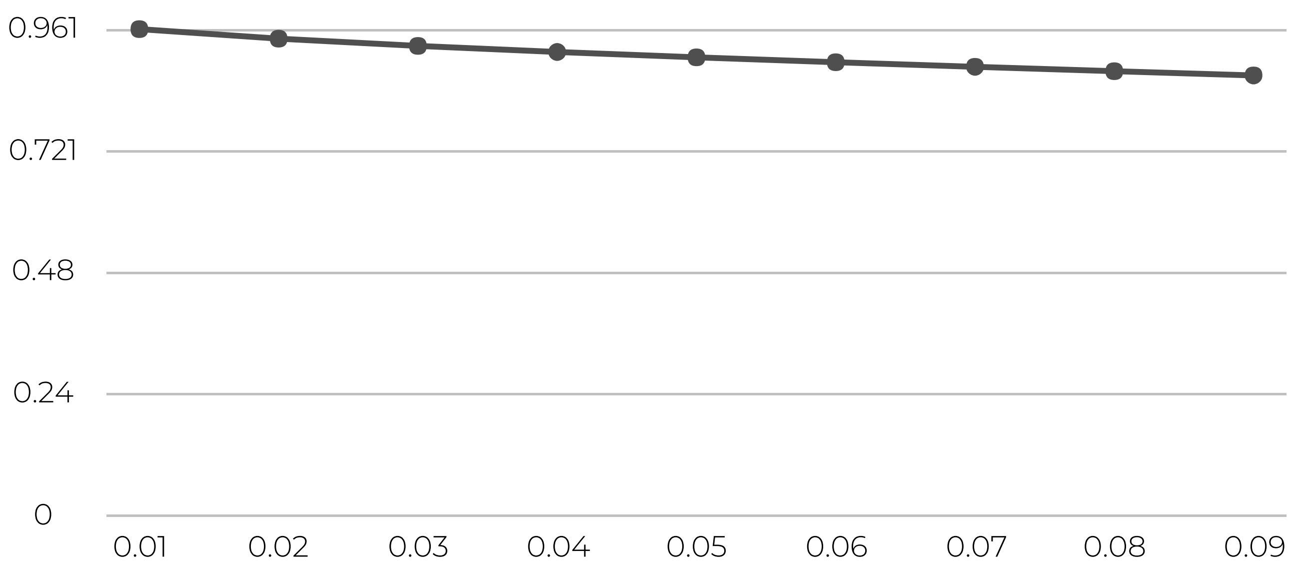
CADMIUM

Cd mole fraction is in linear scale.
Range: 0.01-0.9

Initially, I visualised a relationship between various values of Hg, Cd, Temperature and X. Then, I created a dataset of around 100 values of these 4 variables.
This dataset was fed into a **Multivariate Polynomial Regression** algorithm.
A best fit polynomial function was derived from this dataset.
This relation works in the backend of the application and gives output to the user on the live website.

WEB DEVELOPMENT + MACHINE LEARNING ALGORITHMS

PROJECT OVERVIEW



Graph between Composition and Mercury Mole Fraction

LANGUAGES AND FRAMEWORKS

PYTHON

Backend of.the application is coded in Python using the Flask framework

HTML/CSS/JS

Frontend is designed using HTML, CSS and JavaScript. Boostrap was the framework used.

HOSTING

Website is hosted at remote server on PythonAnywhere.

This whole project was aimed towards building a robust, modern web application to serve data and calculate relevant values for the Liquid Phase Epitaxy Labs at SSPL, DRDO.

The web application can be expanded into giving more variables as output if need be.

MULTIVARIATE POLYNOMIAL REGRESSION

ERROR

THE VALUES GENERATED ARE NOT EXACT BUT A CLOSE APPROXIMATION.

APPROX

THIS APPROXIMATION IS VERY CLOSE TO ACTUAL VALUE. WITHIN 5-10% RANGE.

R-SQUARED VALUE

T: 0.999088
X: 0.846594

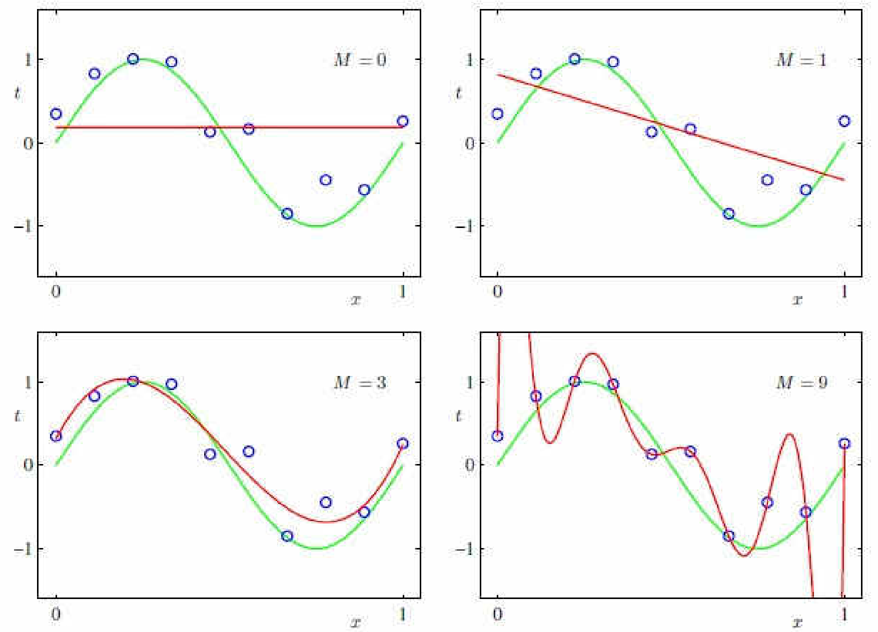


Figure 1.4 Plots of polynomials having various orders M, shown as red curves, fitted to the data set shown in Figure 1.2.

A six degree polynomial function was used as best fit curve for the dataset.

Hg	Cd	T	X
0.01	0.01	455.642	0.96092
0.02	0.02	518.486	0.94203
0.03	0.03	559.859	0.92769
0.04	0.04	591.483	0.91568
0.05	0.05	617.385	0.90508
0.06	0.06	639.484	0.8954
0.07	0.07	658.866	0.88633
0.08	0.08	676.221	0.87766
0.09	0.09	692.026	0.86925
0.1	0.1	706.641	0.86098
0.11	0.11	720.354	0.85276
0.12	0.12	733.416	0.85551
0.13	0.13	746.06	0.83618

MULTIVARIATE POLYNOMIAL REGRESSION

Temperature Dependence:

$$y = -22084.19046\, x_1^6 - 259449.7886\, x_1^5 x_2 - 19790.60393\, x_1^4 x_2^2 + 526755.1452\, x_1^3 x_2^3 + 271390.1683\, x_1^2 x_2^4 - 119032.4739\, x_1 x_2^5 - 130167.9637\, x_2^6 + 79153.79729\, x_1^5 + 428058.1319\, x_1^4 x_2 - 374437.9565\, x_1^3 x_2^2 - 593739.0414\, x_1^2 x_2^3 + 201704.121\, x_1 x_2^4 + 355877.9731\, x_2^5 - 92103.83379\, x_1^4 - 159420.7179\, x_1^3 x_2 + 328449.7966\, x_1^2 x_2^2 - 99476.31544\, x_1 x_2^3 - 368391.5547\, x_2^4 + 39450.3663\, x_1^3 - 13929.45012\, x_1^2 x_2 + 11358.60516\, x_1 x_2^2 + 179794.4495\, x_2^3 - 3998.322269\, x_1^2 - 700.7091274\, x_1 x_2 - 43325.26898\, x_2^2 + 124.9467565\, x_1 + 5844.470387\, x_2 + 411.7137907$$

Composition Dependence:

$$y = -68.79726383\, x_1^6 - 122.8002169\, x_1^5 x_2 + 312.4727987\, x_1^4 x_2^2 + 1083.295821\, x_1^3 x_2^3 + 1222.528714\, x_1^2 x_2^4 + 415.3440347\, x_1 x_2^5 - 167.2300454\, x_2^6 + 224.0952816\, x_1^5 + 231.9338273\, x_1^4 x_2 - 879.8443019\, x_1^3 x_2^2 - 1960.646102\, x_1^2 x_2^3 - 1060.339787\, x_1 x_2^4 + 438.704998\, x_2^5 - 280.5731475\, x_1^4 - 120.8905264\, x_1^3 x_2 + 884.7643711\, x_1^2 x_2^2 + 941.3282927\, x_1 x_2^3 - 432.5780148\, x_2^4 + 164.0174199\, x_1^3 - 38.12726262\, x_1^2 x_2 - 347.336101\, x_1 x_2^2 + 199.1534798\, x_2^3 - 38.02063747\, x_1^2 + 47.85650107\, x_1 x_2 - 43.11470154\, x_2^2 - 5.839509986 \cdot 10^{-1}\, x_1 + 3.983963998\, x_2 + 8.191431013 \cdot 10^{-1}$$

These were the best fit functions used in the backend for calculations

CODE SNIPPETS

```python
from flask import Flask, render_template
from flask_wtf import FlaskForm
from wtforms import FloatField
from wtforms.validators import InputRequired, NumberRange

app = Flask(__name__)
app.config['SECRET_KEY'] = 'Thisisasecret!'

class MyForm(FlaskForm):
    Hg = FloatField('Hg Atomic Fraction', validators=[InputRequired(),NumberRange(min=0.01,max=0.9)])
    Cd = FloatField('Cd Atomic Fraction', validators=[InputRequired(),NumberRange(min=0.001,max=0.9)])

@app.route('/', methods=['GET', 'POST'])
def form():
    form = MyForm()

    if form.validate_on_submit():
        x1 = form.Hg.data
        x2 = form.Cd.data
```

```html
<div class="container theme-showcase" role="main">

      <div class="row">
        <div class="col-lg-12">
          <div class="well bs-component">
            <form class="form-horizontal", method="POST" action="/">
              {{ form.csrf_token }}
              <fieldset>
                <legend>MCT Phase Calculator</legend>
                {{ render_field(form.Hg) }}  {{ render_field(form.Cd) }}
                <div class="form-group">
                  <div class="col-lg-10 col-lg-offset-2">
                    <button type="reset" class="btn btn-default">Cancel</button>
                    <button type="submit" class="btn btn-primary">Submit</button>
                  </div>
                </div>
              </fieldset>
            </form>
          </div>
        </div>
```

MERCURY CADMIUM TELLURIDE

MCT HAS ZINCBLENDE STRUCTURE

TWO FCC CUBIC LATTICES

MCT HAS HIGH ELECTRON MOBILITY

ELECTRONS HAVE LONG BALLISTIC LENGTH

WIDELY USED FOR INFRARED DETECTION

HgCdTe or mercury cadmium telluride (also cadmium mercury telluride, MCT, MerCad Telluride, MerCadTel, MerCaT or CMT) is an alloy of cadmium telluride (CdTe) and mercury telluride (HgTe) with a tuneable bandgap spanning the shortwave infrared to the very long wave infrared regions. The amount of cadmium (Cd) in the alloy can be chosen so as to tune the optical absorption of the material to the desired infrared wavelength. CdTe is a semiconductor with a bandgap of approximately 1.5 electron volts (eV) at room temperature. HgTe is a semimetal, which means that its bandgap energy is zero. Mixing these two substances allows one to obtain any bandgap between 0 and 1.5 eV

SEMICONDUCTORS AND EPITAXY

A **semiconductor** material has an electrical conductivity value falling between that of a conductor(copper, gold) and an insulator(glass). Their resistance decreases as their temperature increases. Their conducting properties may be altered in useful ways by the deliberate, controlled introduction of impurities ("doping") into the crystal structure. Where two differently-doped regions exist in the same crystal, a semiconductor junction is created. The behaviour of charge carriers which include electrons, ions and electron holes at these junctions is the basis of diodes, transistors and all modern electronics. Semiconductor devices can display a range of useful properties such as passing current more easily in one direction than the other, showing variable resistance, and sensitivity to light or heat. Because the electrical properties of a semiconductor material can be modified by doping, or by the application of electrical fields or light, devices made from semiconductors can be used for amplification, switching, and energy conversion. The conductivity of silicon is increased by adding a small amount of pentavalent (antimony,phosphorus, or arsenic) or trivalent (boron, gallium, indium) atoms. This process is known as doping and these semiconductors are known as doped or extrinsic semiconductors. The modern understanding of the properties of a semiconductor relies on quantum physics to explain the movement of charge carriers in a crystal lattice. When a doped semiconductor contains mostly free holes it is called "p-type", and when it contains mostly free electrons it is known as "ntype". Semiconductors used in electronic devices are doped under precise conditions to control the concentration and regions of p-type and n-type dopants.

Epitaxy refers to the deposition of a crystalline over layer on a crystalline substrate. The over layer is called an epitaxial film or epitaxial layer. The term epitaxy comes from the Greek roots epi, meaning "above", and taxis meaning "an ordered manner". It can be translated as "arranging upon". For most technological applications, it is desired that the deposited material form a crystalline over layer that has one well-defined orientation with respect to the substrate crystal structure (single-domain epitaxy). Epitaxial films may be grown from gaseous or liquid precursors. Because the substrate acts as a seed crystal, the deposited film may lock into one or more crystallographic orientations with respect to the substrate crystal. If the over layer either forms a random orientation with respect to the substrate or does not form an ordered over layer, it is termed non-epitaxial growth. If an epitaxial film is deposited on a substrate of the same composition, the process is called homoepitaxy; otherwise it is called heteroepitaxy Various epitaxy methods like Vapour Phase Epitaxy(VPE), Liquid Phase Epitaxy (LPE), Molecular Beam Epitaxy (MBE) exist. Epitaxy is used in nanotechnology and in semiconductor fabrication. Indeed, epitaxy is the only affordable method of high quality crystal growth for many semiconductor materials. In surface science, epitaxy is used to create and study monolayer and multilayer films of adsorbed organic molecules on single crystalline surfaces. Adsorbed molecules form ordered structures on atomically flat terraces of single crystalline surfaces and can directly be observed via scanning tunnelling microscopy. In contrast, surface defects and their geometry have significant influence on the adsorption of organic molecules

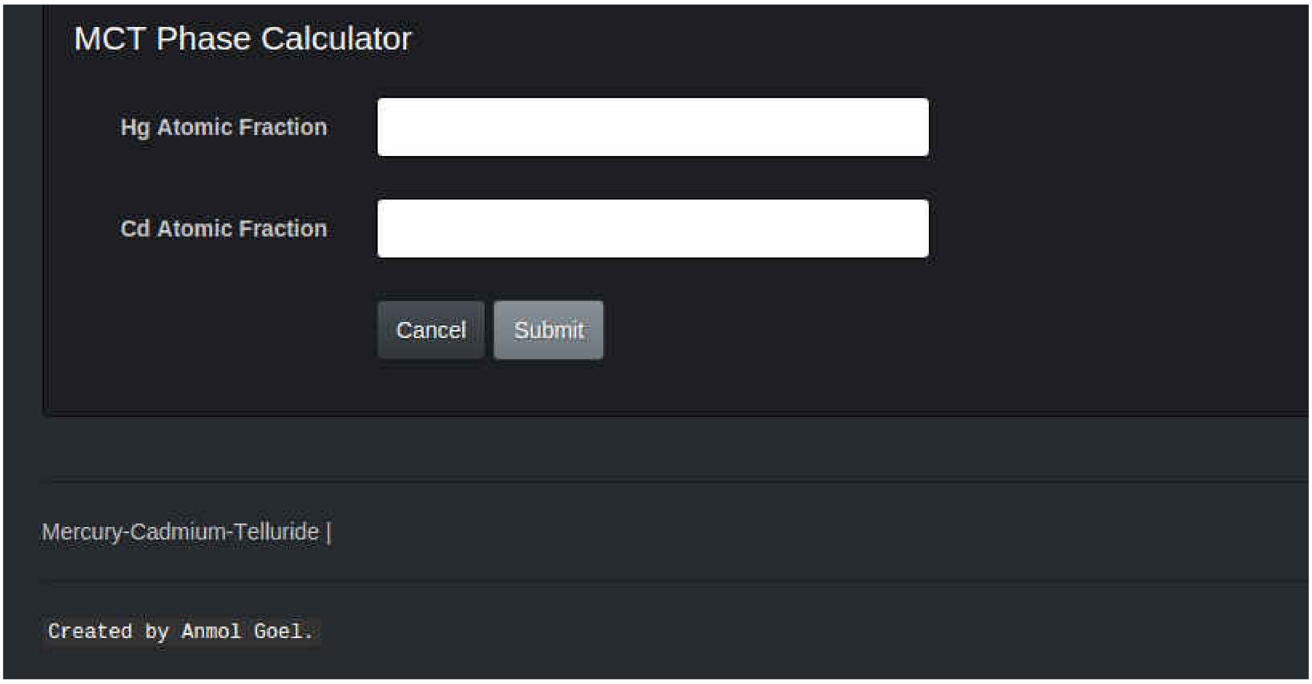
LIQUID PHASE EPITAXY

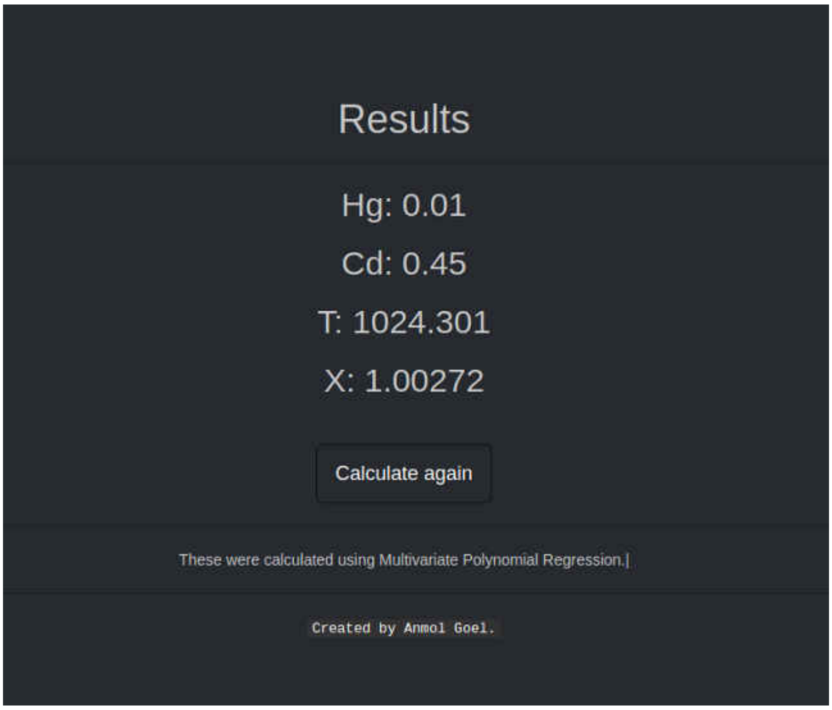
Liquid-phase epitaxy (LPE) is a method to grow semiconductor crystal layers from the melt on solid substrates. This happens at temperatures well below the melting point of the deposited semiconductor. The semiconductor is dissolved in the melt of another material. At conditions that are close to the equilibrium between dissolution and deposition, the deposition of the semiconductor crystal on the substrate is relatively fast and uniform. The most used substrate is indium phosphide (InP). Other substrates like glass or ceramic can be applied for special applications. To facilitate nucleation, and to avoid tension in the grown layer the thermal expansion coefficient of substrate and grown layer should be similar.

There are three principle of growth technique: tipping, dipping and sliding. In the tipping technique, the substrate is held tightly at the upper end of a graphite boat and the growth solution is placed at the other end. The solution is brought into contract with the substrate by the tipping substrate. The furnace is then cooled an epitaxial layer is grown an the substrate. The solution remains in contact with the substrate for the defined temperature interval and growth is terminated by tipping the furnace back to its original position. The solution remaining surface is removed by wiping and dissolving in a suitable solvent.

The dipping technique uses a vertical furnace. The solution is contained in a graphite or alumina crucible at the lower end of the furnace. The substrate fixed in a movable holder is initially positioned above the solution. At the desired temperature by immersing the substrate in the solution and it is terminated by withdrawal of the substrate from the solution. The sliding techniques uses a multibin graphite boat to grow multiple epitaxial layers. The principle components of this apparatus are a massive split graphite barrel with a graphite slider, a fused silica growth tube to provide a protective atmosphere and a horizontal resistance furnace.

WEBSITE SCREENSHOTS





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