Department of
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Multi-Physics Formulation of Laser Powder Based Fusion Process

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Contents

Definition

- **Laser Powder Bed Fusion (LPBF)** is a **Selective Laser Melting(SLM) technique** in which a high laser power implements on metal powder bed which melts and fuses together to get the desired structure as per 3-D CAD model.

- Successive layers of powders are deposited and fused, enabling the production of complex, high-performance metal components with fine geometrical accuracy.

- LPBF operates with interaction of different Multi-Physics.

- These principles enable precise control over melting , fusion, solidification and microstructure formation.

- Its transformative potential spans its uses in different industries like Aerospace, Medical, Automotive, Energy etc..

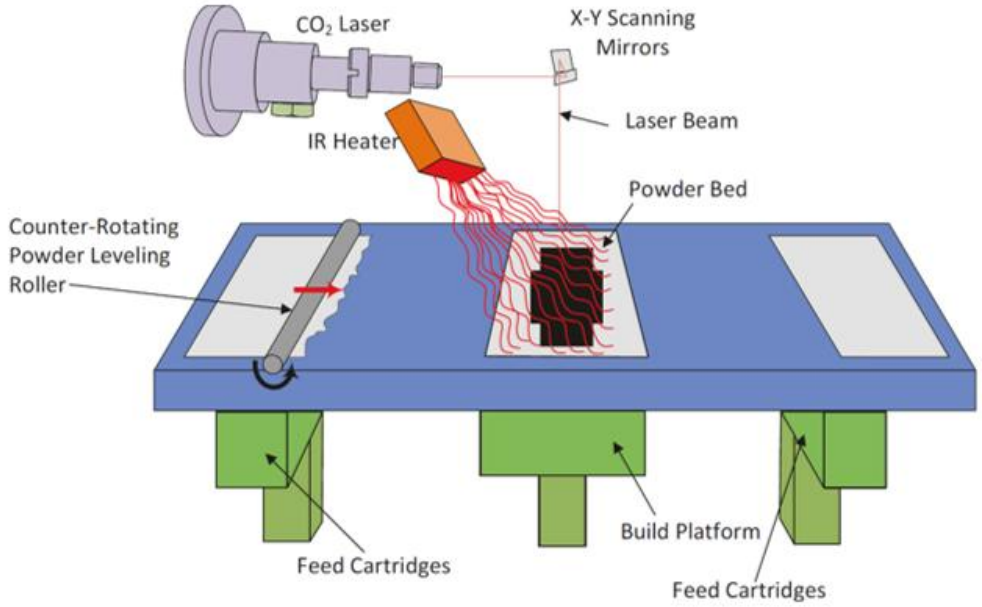


Fig.1. Schematic Diagram of SLM

- When a part is formed using the LPBF process, many phenomenon occur—including heating, melting, cooling, and solidification—which can cause a variety of defects such as improper fusion, cracks, and pore formation that may lead to product failure.

- Therefore, for the reliable development of ready-to-use final parts, the Multi-Physics responsible for these events during the LPBF process must be incorporated into simulation and process control.

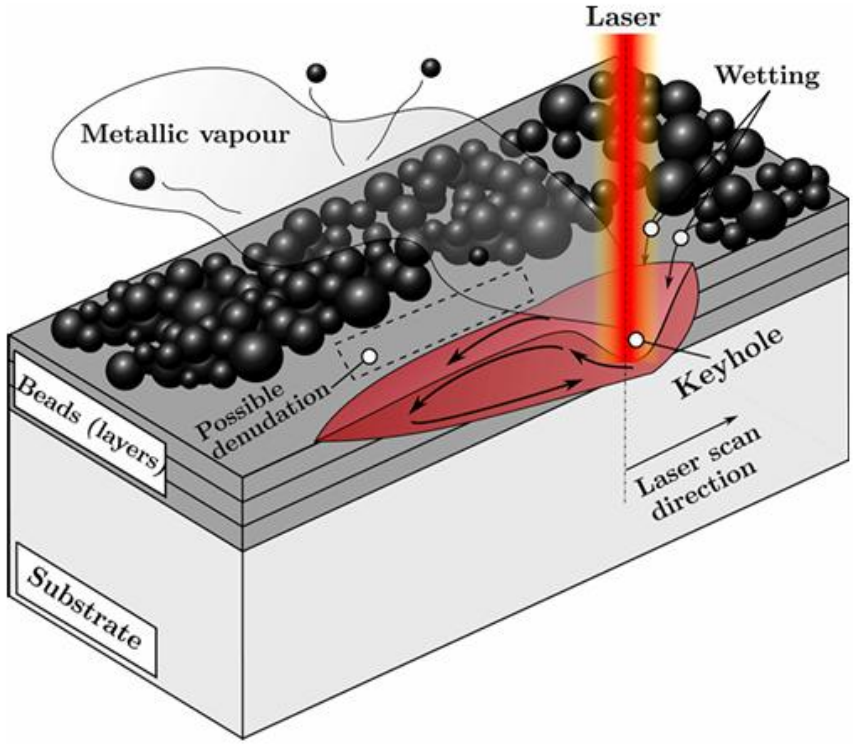
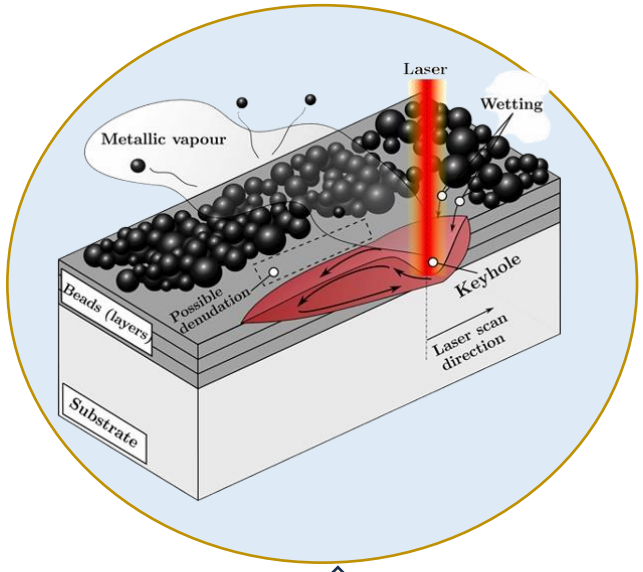


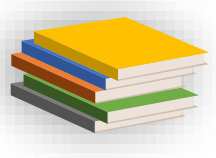
Fig.2. Schematic diagram of LPBF process showing multiple phenomenon happening during the process

Multi-Physics Framework For LPBF Simulation



- ✓ Thermodynamics
  - ✓ Heat Transfer
    - ✓ Conduction
    - ✓ Convection
    - ✓ Radiation
- ✓ Fluid Dynamics
  - ✓ Marangoni Convection
  - ✓ Recoil Pressure
  - ✓ Phase Transformation
- ✓ Solid mechanics
  - ✓ Residual Stresses

Literature Review



Author *Publication (Year)*	Physics Applied	Findings	Remarks
Nandi and Dattatraya (2021 and 2022)	Heat Transfer and Fluid Dynamics	The dimensions of melt-pool are computed .	Only Marangoni convection is applied can be extend for recoil and 3D and Multi-material.
Queva et al.(2020)	Fluid Dynamics	study of the impact of vaporisation on melt pool dynamics in Laser Powder Bed Fusion	FEM model developed using different physics.
Gada and Sharma (2014)	Phase transformation	Level set formulation for two phase flow	Implemented only for general case not for LPBF or anything.
Qian and Chen (2017)	Heat transfer and Fluid Dynamics	The temperature field, the velocity field, and the interface between liquid and gas phases.	Moving laser heat source can be applied to simulate LPBF process.
Li et al.(2020)	Heat Transfer and Fluid Dynamics	New variational level set formulation that completely eliminates the need of the re initialization	FEM model developed

Literature Review

Author *Publication (Year)*	Physics Applied	Findings	Remarks
Li et al.(2018)	Marangoni convection	CFD-based model is applied to study the melt pool interaction between adjacent tracks and pores formation under the multi-track conditions in LPBF process	Different physics can be applied for multilayer
Foroozmehr et al.(2016)	Heat Transfer and Fluid Dynamics	The model adopt the Optical Penetration Depth(OPD) of laser beam in to the powder bed and its dependency on the powder size in definition of the heat source.	FEM model used , CFD model can also developed
Chen et al.(2023)	Heat transfer and Marangoni Convection	Simulation of melt pool size and flow evolution for laser powder bed fusion of powder grade Ti6Al4V	Model developed on FLOW-3D sotware.
CHANG et al.(2017)	Heat Transfer and Fluid Dynamics	A level set formulation is derived for incompressible, immiscible smooths out the front. In the case of irrotational flow, one Navier–Stokes equations separated by a free surface	Multi-physics can be applied for a more accurate model for the LPBF
Peng et al.(1999)	Multiphase flow	A fast method to localize the level set method	More physics can be applied

Research Gap

1. Implementation of Multi-Physics in LPBF Models

- Current research on LPBF often focuses on isolated aspects such as heat transfer or fluid flow. However, LPBF is inherently a **multi-physics process**, involving interactions between **thermal, fluid flow, phase transformation, and vapor dynamics**.

- A **comprehensive virtual model** that integrates all these coupled physics is still lacking, which limits the accuracy of predicting melt pool behavior and defect formation.

2. Identifying the Dominant Physical Phenomenon

- While multiple physics are active during LPBF, it is still not well known that **which phenomenon have the strongest influence** on melt pool geometry, stability, and defect formation (e.g., recoil pressure vs. thermal gradients vs. Marangoni convection).

- A systematic study is required to **quantify the relative influence** of each physical mechanism, which will help in **prioritizing modeling efforts and improving simulation accuracy**.

3. Computationally Efficient Model

- A computationally efficient model still need to be developed as when more physics involved more time for the simulation the model will take.

Objectives

- **Incorporation of Phase Transformation in LPBF** using Level Set Method.
- **Incorporation of Different Physical Phenomenon like Marangoni Convection and Recoil Pressure.**
- **Systematic study** and **validation.**

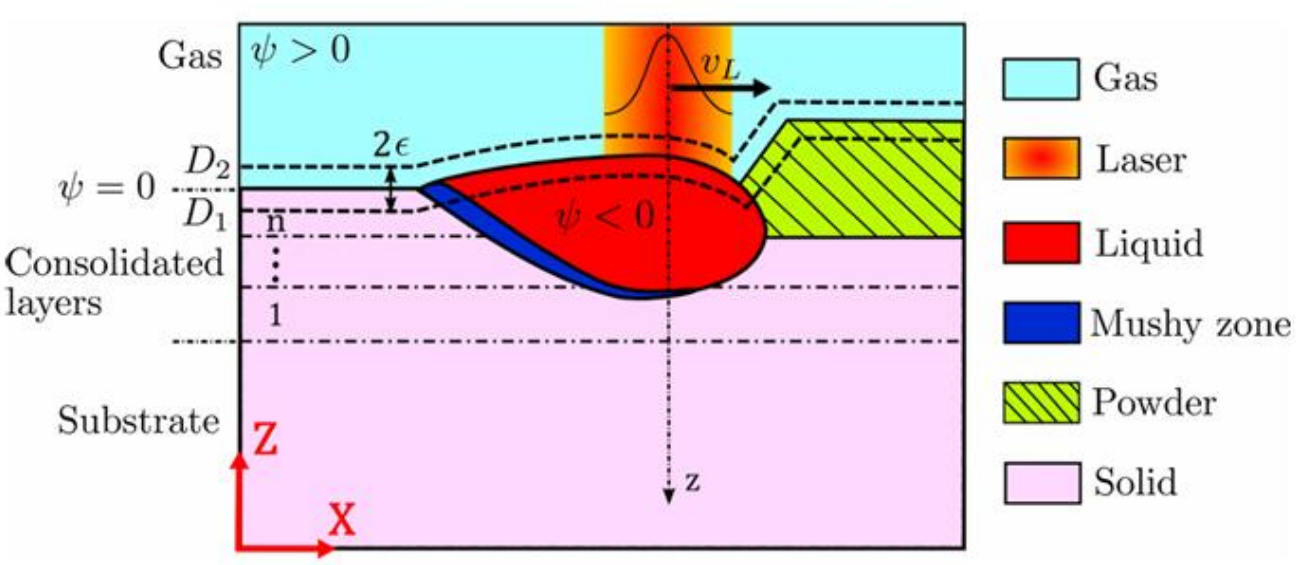


Fig.3. Schematic of LPBF process with the application of recoil pressure

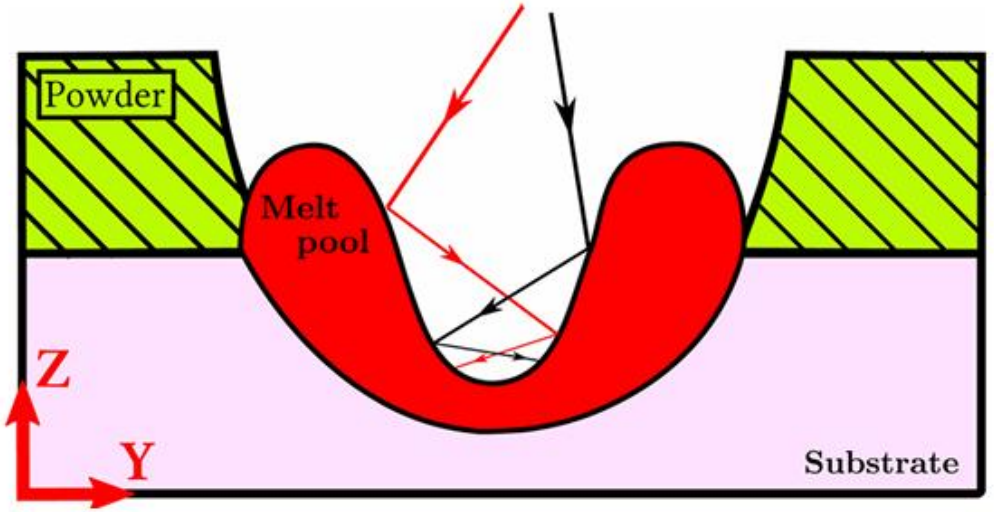


Fig.4. Schematic of LPBF process with the application of recoil pressure

Ongoing Work

- **Level set method has been used for two phase flow which includes level set function, Heaviside function(to the average the physical surrounds the interface), Dirac-Delta function, mass ,momentum and energy equation for the development of phi , velocity and temperature field.**

- **Application of Level set method for LPBF process with the implementation of moving heat source and temperature dependent thermal properties.**

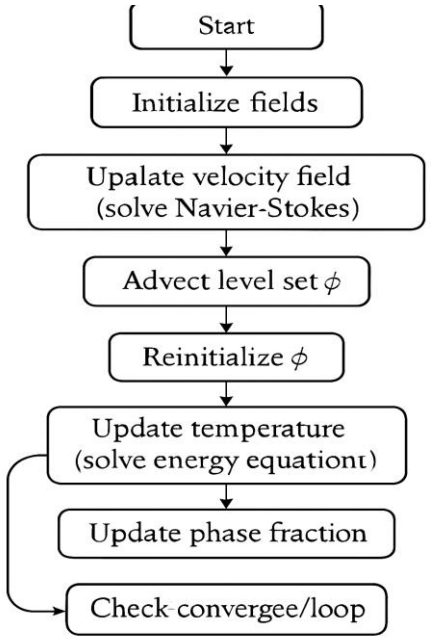


Fig.5. Flow chart of Level Set Method

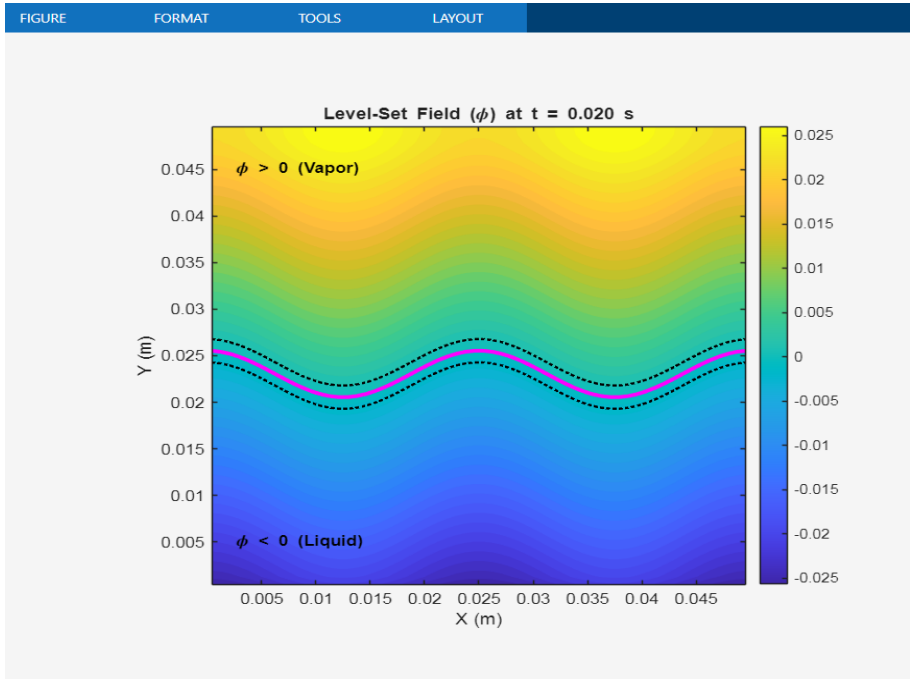
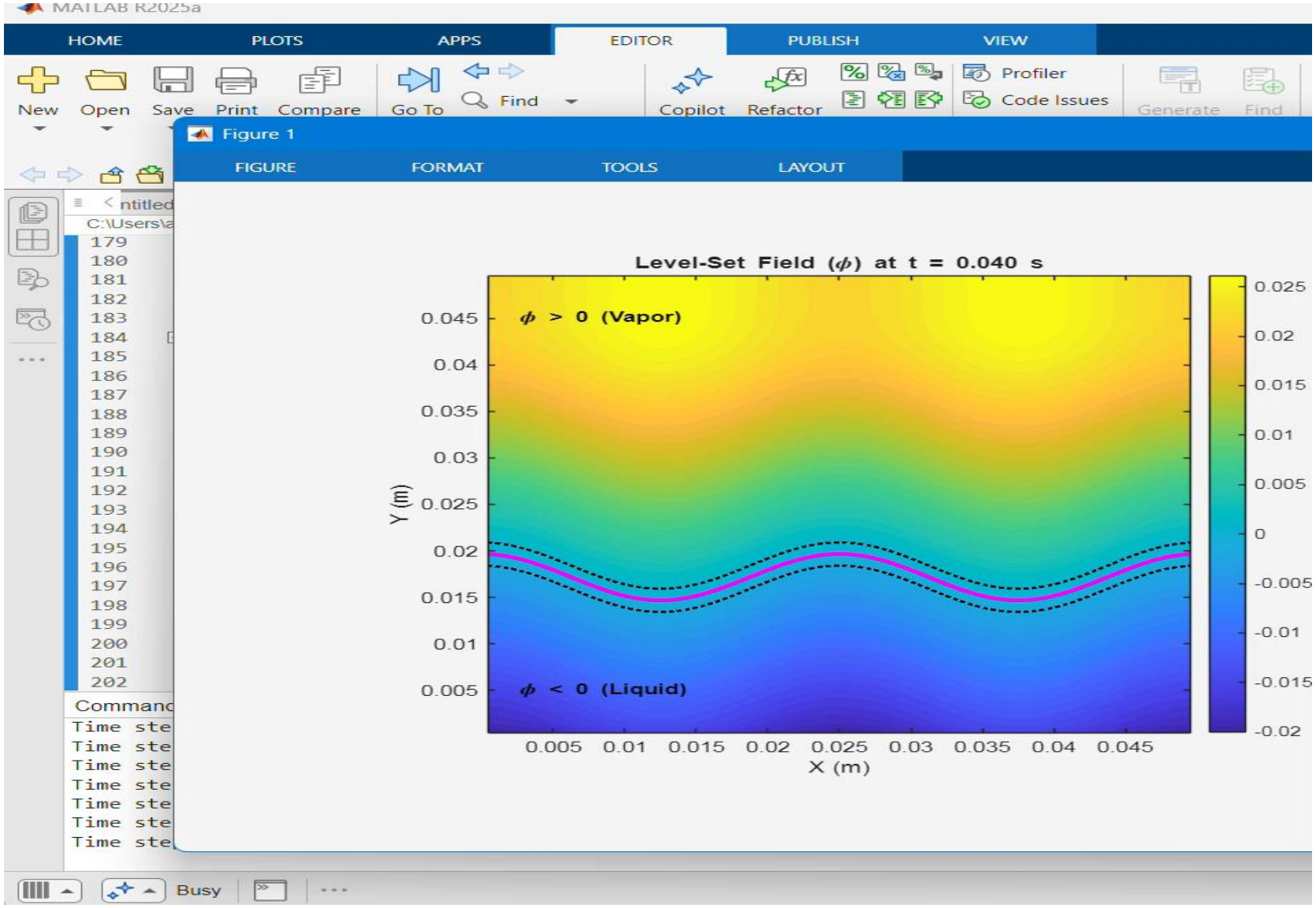


Fig.6. Result of simulation for water with base temperature at 373 kelvin

Result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Profiler
Code Issues
Generate
Find
Figure 1
FIGURE
FORMAT
TOOLS
LAYOUT
Level-Set Field (ϕ) at t = 0.040 s
ϕ > 0 (Vapor)
ϕ < 0 (Liquid)
Y (m)
X (m)
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.025
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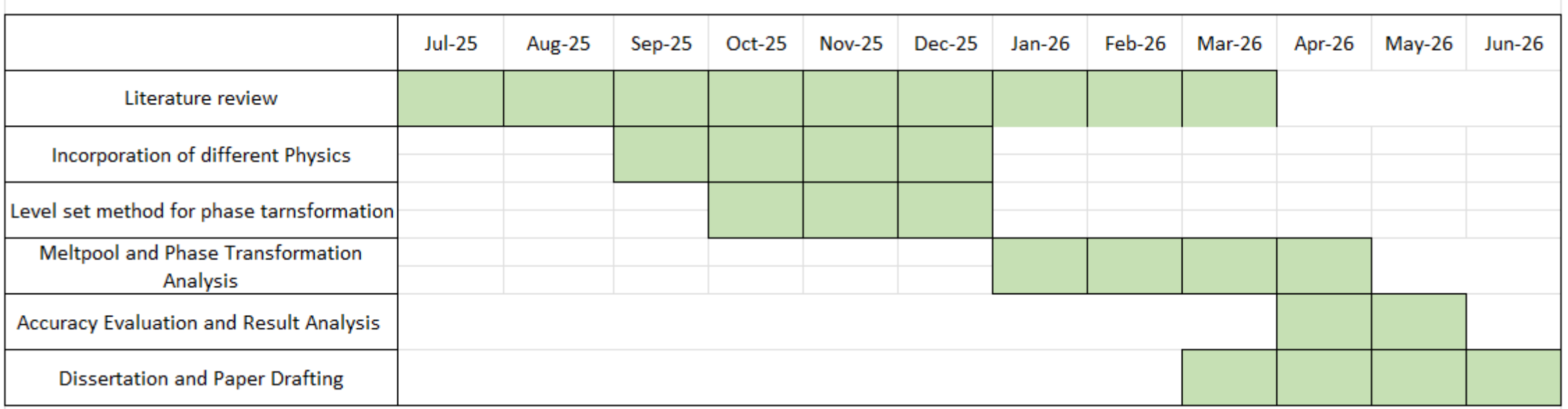
Busy

Timeline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Literature review
Incorporation of different Physics
Level set method for phase tarnsformation
Meltpool and Phase Transformation Analysis
Accuracy Evaluation and Result Analysis
Dissertation and Paper Drafting

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Thank You