Computational Investigation of Transport Processes during High Energy Materials Processing Application using a Hybrid Lattice Boltzmann Model

Dipankar Chatterjee*

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Abstract

A three dimensional numerical simulation is performed in order to understand the transport of mass, momentum and heat during high energy materials processing applications using a hybrid lattice Boltzmann (LB) model. The underlying hydrodynamics is addressed through an evolution equation of a single-particle density distribution function following the conventional LB approach, whereas, the macroscopic temperature and compositional fields are obtained by solving auxiliary scalar transport equations. The solid-liquid phase changing aspects are incorporated into the hydrodynamic LB model by inserting appropriate source terms in the evolution equation through the most formal technique following the extended Boltzmann equations along with an adapted enthalpy updating scheme in association with the classical enthalpy-porosity technique. A high power laser surface alloying process is simulated using the developed model and excellent agreement with the available experimental results is observed.

Keywords: Numerical simulation; Hybrid lattice Boltzmann model; Laser surface alloying; Materials processing; Microstructure prediction

1. Introduction

High power laser assisted manufacturing processes such as laser cutting, laser drilling, laser cladding and laser surface alloying (LSA) are considered to be the most modern process of molten metal applications. In these processes the work pieces are locally melted by an intense energy source (such as the laser), followed by solidification and sometimes with a simultaneous feeding of some extraneous alloying element (as in case of LSA) within the laser-generated molten pool. The mechanical strength and the microstructure of the resolidified zone are strongly dependent on the thermal histories in the fusion zone and the nearby unmelted regions. Furthermore, fluid flow and
species transport within the molten pool are known to have considerable effects on these thermal histories and solidification processes. Therefore, in order to predict the thermo-solutal behavior of the process accurately, it is very important to have a thorough knowledge of the transport mechanism inside the laser molten pool, which leads to a final resolidified microstructure.

Computational investigation of transport processes in high energy laser assisted materials processing applications (for example, LSA) have been a subject of intense research for several decades. The earlier models are mostly based on the conventional CFD (Computational Fluid Dynamics) approaches (Sarkar et al., 2002; Chakraborty et al., 2004; Chatterjee and Chakraborty, 2005a, 2006a). It needs to be emphasized here that typically alloy solidification is multiscale in nature since it occurs in disparate length and time scales. Interactions among thousands or even millions of crystals give the overall behavior of the solidification process and define the properties of the final product. Investigations of the interactions and growth of crystals in the microscale are quiet computationally intensive, whereas macroscale models lack accuracy since these are based on large number of simplifications. Multiscale modeling by coupling the macroscopic and microscopic models allows us to take advantage of both the efficiency of the macroscopic models and the accuracy of the microscopic models. These have already been established through a series of recent articles while simulating the generalized convection-diffusion phase change problems typically encountered in high power materials processing applications (Chatterjee and Chakraborty, 2005b, 2006b, 2007, 2008; Chatterjee, 2009, 2010).

We aim here to couple both the macroscopic and microscopic modeling strategies within a mesoscopic framework by developing a hybrid lattice Boltzmann model. In this model, the hydrodynamics is going to be monitored through an evolution equation involving a single particle density distribution function following the conventional lattice Boltzmann technique. The thermal and solutal transports will be addressed by the classical macroscopic approach. The phase change aspect will be handled by a fixed-grid enthalpy-porosity approach (Brent et al., 1988) in a thermodynamically consistent manner. The source terms originating out of the physical situation are going to be incorporated into the evolution equation by the most formal technique following the extended Boltzmann equation. The proposed model will finally be applied to simulate a typical high power LSA process.

2. Mathematical formulation

2.1 Physical description of the problem
A typical laser surface alloying process is shown in Fig 1., in which a continuous-beam laser moves with a constant scanning speed, $u_s$, along the negative x-direction. The intense heat from the laser beam strikes the substrate surface and contributes to the formation of a molten pool. As the pool reaches a completely molten state, an alloying element in the form of powder is added to the molten pool. The powder melts and mixes with the molten base metal by convection and diffusion. As the laser source moves away from the location where the pool is already developed, resolidification of the zone occurs which leads to a final resolidified microstructure. In the present study, iron is considered as the base metal (substrate) and aluminum as the alloying element for simulation purposes. Following simplifying assumptions are made in the mathematical formulation:
1. The alloying material is introduced in a molten state and it exists as a dilute solute in the molten pool.
2. The molten metal is considered to be Newtonian and incompressible.
3. The density variation owing to thermo-solutal effect is taken care of by Boussinesq approximation.

![Fig. 1. Schematic diagram of a typical laser surface alloying process.](image)

### 2.2 Continuum conservation equations

Since it is a moving heat source problem, the transport phenomena occurring inside the molten pool can be conveniently studied with respect to a co-ordinate system that translates with the laser heat source and accordingly, the following co-ordinate transformation is introduced:

\[
x = x' - (u_s) t
\]

where the negative sign in front of \( u_s \) indicates scanning is in the negative \( x \) direction (as shown in Fig. 1), \( x, y \) and \( z \) are the co-ordinates in a frame moving with the laser torch. Applying the above transformation, the equivalent single-phase volume-averaged continuum conservation equations (Brent et al., 1988), appropriate for the thermo-fluidic transport in presence of melting/solidification can be described as:

\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0
\]

\[
\frac{\partial (\rho \mathbf{u})}{\partial t} + \nabla \cdot (\rho \mathbf{u} \mathbf{u}) = -\nabla p + \nabla \cdot (\mu \nabla \mathbf{u}) + \rho (\mathbf{G} + \mathbf{S} + \mathbf{S}_M)
\]

\[
\frac{\partial (\rho c_p T)}{\partial t} + \nabla \cdot (\rho c_p \mathbf{u} T) = \nabla \cdot (k \nabla T) + \dot{q} + \rho \mathbf{S}_T
\]

\[
\frac{\partial (\rho C)}{\partial t} + \nabla \cdot (\rho \mathbf{u} C) = \nabla \cdot (D \nabla C) + \rho \mathbf{S}_C
\]

where \( \rho, \mathbf{u}, T, C \) and \( p \) are the density \([\text{kg/m}^3]\), velocity \([\text{m/s}]\), temperature \([\text{K}]\), species concentration and pressure \([\text{N/m}^2]\), respectively. \( \mu, c_p, k \) and \( D \) respectively, are the dynamic
viscosity \([\text{Pa S}]\), specific heat \([\text{J/Kg K}]\), thermal conductivity \([\text{W/m K}]\) and mass diffusivity \([\text{m}^2/\text{s}]\) of the thermodynamic system under consideration. In Eq. (3), \(G\) is the thermo-solutal buoyancy term and can be described as:

\[
G = g \left[ \beta_T (T - T_{\text{ref}}) + \beta_C (C - C_{\text{ref}}) \right],
\]

where \(g\) is the acceleration due to gravity \([\text{m/s}^2]\), \(\beta_T\) and \(\beta_C\) are the volumetric expansion coefficients of heat \([1/\text{K}]\) and solute respectively, \(T_{\text{ref}}\) \([\text{K}]\) is taken to be equal to the melting temperature of the base material and \(C_{\text{ref}}\) is the concentration of the alloying species at that reference temperature. The term \(S\), appearing in Eq. (3), represents an equivalent frictional resistance force per unit mass, which originates from the consideration that the morphology of the phase-changing domain can be treated as an equivalent porous medium that offers a frictional resistance towards fluid flow in that region. Mathematically, this can be represented as:

\[
S = -R \cdot \mathbf{u} = -\left( \frac{\mu}{\rho} \right) K^{-1} \cdot \mathbf{u}
\]  

where \(R\) represents an equivalent resistance tensor and \(K\) is the permeability tensor and can be given following the Darcy model for flow through a porous medium, in association with the Cozeny-Karman equation (Voller and Prakash, 1987), as:

\[
\frac{\mu}{K^{-1}} = \kappa \left[ \frac{(1 - f_i)^2}{f_i^3 + \varepsilon} \right]
\]  

where \(\kappa\) is a morphological constant and \(\varepsilon\) is a computational constant introduced to avoid division by zero. Further, \(f_i\) is the liquid fraction, given as \(f_i = \Delta H / L\), where \(L\) is the latent heat of phase change and \(\Delta H\) is the latent enthalpy of a computational cell undergoing phase change. In Eq. (7), the term \(f_i\) is considered to mimic an equivalent ‘porosity’ of the cells undergoing phase transition, as per enthalpy-porosity formulation (Voller & Prakash, 1987). \(\Delta H\) can be prescribed as:

\[
\Delta H = f(T) = L : T > T_i \\
= f_i L : T_i \leq T \leq T_l \\
= 0 : T < T_s
\]  

where \(T_s\) and \(T_l\) are the solidus and liquidus temperatures respectively. The above formulation effectively ensures that in phase changing cells, the porous medium resistance term in Eq. (3) dominates over the transient, convective and diffusive effects originating out of molecular interaction mechanisms, thereby forcing the velocity field to imitate the Kozeny-Carman law. On the other hand, in totally solid elements \((f_i = 0)\), a large magnitude of the porous medium resistance term forces any velocity predictions effectively to zero. In a fully-liquid element \((f_i = 1)\), however, this term has no consequence, and the usual form of Navier Stokes equation can be retrieved. In essence, it can be summarized that the term, \(S\), effectively controls the degree of penetration of the convective field into the interdendritic region.

The latent heat evolution is accounted for by defining a source term in the macroscopic energy conservation equation (second term on the RHS of Eq. (4)) as:

\[
\dot{q} = -\left[ \frac{\partial (\rho \Delta H)}{\partial t} + \nabla \cdot (\rho \mathbf{u} \Delta H) \right]
\]  

55
Finally, the terms $S_M = -u_x \frac{\partial u}{\partial x}$, $S_T = -u_x \frac{\partial T}{\partial x}$ and $S_C = -u_x \frac{\partial C}{\partial x}$ appearing in Eqs. (3-5) are the momentum, energy and species sources respectively originating out as a result of the coordinate transformation.

The boundary conditions for the thermal, solutal and flow variables with reference to the work piece can be stated as follows:

**Heat transfer and fluid flow boundary conditions**

Considering Gaussian heat input, convective and radiation loss, the top surface thermal boundary condition can be written as:

$$-k \frac{\partial T}{\partial y} = -q''(r) + h(T - T_\infty) + \varepsilon_r \sigma_{rad} (T^4 - T^4_x)$$

where $q''(r)$ is the net arc heat flux distributed in a Gaussian manner with a radius of $r_q$ and given by:

$$q''(r) = \frac{\eta P}{\pi r_q^2} \exp \left(-\frac{r^2}{r_q^2}\right) : 0 \leq r \leq r_q$$

$$= 0 \quad : \text{otherwise}$$

where $\eta$ is the efficiency of the laser heating, $P$ represents the total laser power and $r$ is defined as $r^2 = (x-x_0)^2 + (z-z_0)^2$ with $(x_0, z_0)$ being the coordinate of the laser tip on the top surface and the sign of the heat flux corresponds to the heat flux is in the negative $y$ direction; $h$ is the convective heat transfer coefficient, $\varepsilon_r$ is the emissivity of the top surface and $\sigma_{rad}$ is the Stefan-Boltzmann constant; $T_\infty$ is the ambient temperature. Assuming a flat top surface (He et al., 1995) the vertical mean velocity can be given as:

$$v = 0$$

From the free surface shear balance between viscous force and surface tension:

$$\mu \frac{\partial u}{\partial y} = \frac{\partial \sigma_{sur}}{\partial T} \frac{\partial T}{\partial x} + \frac{\partial \sigma_{sur}}{\partial C} \frac{\partial C}{\partial x}$$

$$\mu \frac{\partial w}{\partial y} = \frac{\partial \sigma_{sur}}{\partial T} \frac{\partial T}{\partial z} + \frac{\partial \sigma_{sur}}{\partial C} \frac{\partial C}{\partial z}$$

where $\frac{\partial \sigma_{sur}}{\partial T}$ and $\frac{\partial \sigma_{sur}}{\partial C}$ are the surface tension coefficients of temperature and concentration respectively.

The four side faces are subjected to convective heat transfer boundary condition:

$$-k \frac{\partial T}{\partial n} = h(T - T_\infty)$$

where $n$ is the direction of outward normal to the surface concerned. The bottom face being insulated, the temperature boundary condition is given by:
\[ \frac{\partial T}{\partial y} = 0 \]  

**(Mass transfer boundary conditions)**

Mass flux of the added species at the top surface can be represented using Fick’s first law of diffusion as

\[ -\rho D \frac{\partial C}{\partial y} = -\dot{m} \]  

where \( \dot{m} \) is the mass flux of the alloying element in the negative \( y \) direction. The mass flux is assumed to be uniform and is calculated from the powder feed-rate \( (m_f) \) as

\[ \dot{m} = \frac{m_f}{A} \]  

where \( A \) is the instantaneous molten area at the top surface. It can be noted here that the alloying element added to the pool subsequently mixes with the molten base metal by convection and diffusion. However, at the solidification interface, only a part of solute \( k_p C \) goes into the solid phase, where \( k_p \) is the partition coefficient. Thus, the solute flux balance at the solidification front is given by (Flemings, 1974):

\[ -D \frac{\partial C}{\partial n} = v_n C \left(1 - k_p \right) \]  

where \( v_n \) is the interface velocity in that direction. Similarly, the boundary condition at the fusion front can be written as (Flemings, 1974):

\[ -D \frac{\partial C}{\partial n} = v_n C \]  

**2.3 The lattice Boltzmann model**

A statistical description of a fluid system can be made in terms of a particle density distribution function, which satisfies the continuous Boltzmann equation with a single-relaxation-time BGK (Bhatnagar-Gross-Krook) model (Bhatnagar et al., 1954) as:

\[ \partial_t f + \xi \cdot \nabla f = -\left( f - f^{eq} \right)/\lambda + F \]  

where \( f(x, \xi, t) \) is a single particle density distribution function from which the macroscopic properties of the fluid can be obtained, \( \xi \) is the microscopic velocity, \( \lambda \) is the relaxation time, \( F \) and \( f^{eq}(x, \xi, t) \) are the external forcing parameter and the Maxwell-Boltzmann type equilibrium distribution function, given by,

\[ F = \frac{\left(G + S + S_M \right) \cdot \left(\xi - U\right)}{RT} \]  

\[ f^{eq} = \frac{\rho}{(2\pi RT)^{\Delta^2}} \exp \left[-\frac{(\xi - U)^2}{2RT}\right] \]  

where \( R \) (\( \approx 1 \), as per the conventional LB methodology) is the gas constant and \( \Delta \) is the dimensionality (for example, \( \Delta = 2 \) for two-dimension and \( \Delta = 3 \) for three-dimension). The macroscopic variables are obtained by taking (microscopic velocity) moments of the density...
distribution function $f$ as: 
$$
\rho = \int f \, d\xi, \quad \rho \mathbf{u} = \int f \mathbf{u} \, d\xi + \rho (\mathbf{G} + \mathbf{S} + \mathbf{S}_m).
$$
However, it is a well-known fact that the temperature field obtained from the second moment of the distribution function $f$ yields a fixed Prandtl number ($Pr$), implying that the thermal diffusivity cannot be adjusted independently of the kinematic viscosity (He et al., 1998), which restricts its applicability to a limited class of problems only.

Eq. (21) can now be represented by the following generic discrete-velocity form:
$$
\partial_t f_i + \xi_i \cdot \nabla f_i = -\left( f_i - f_i^{eq} \right) / \lambda + F_i,
$$
where $i \in \{1, b\}$ stands for the $b$ base vectors of the underlying lattice type. Eq. (23) is subsequently integrated along its characteristic using the second order trapezoidal rule (He et al., 1998) to yield the following discrete evolution equation:
$$
\begin{align*}
\frac{\delta t}{2} \left[ f_i \left( \mathbf{x} + \xi_i \partial_t, \xi_i, t + \delta t \right) - f_i \left( \mathbf{x}, \xi_i, t \right) \right] &= -\frac{\delta t}{2} \left[ f_i \left( \mathbf{x}, \xi_i, t \right) - f_i^{eq} \left( \mathbf{x}, \xi_i, t \right) \right] + \frac{\delta t}{2} F_i \left( \mathbf{x}, \xi_i, t \right) + \frac{\delta t}{2} F_i \left( \mathbf{x} + \xi_i \partial_t, \xi_i, t + \delta t \right) .
\end{align*}
$$
where $\delta t$ denotes the time step. The forcing parameter and the discrete equilibrium distribution functions can be constructed as:
$$
F_i = w_i \rho \left[ \frac{\xi_i - \mathbf{u} \cdot \xi_i}{c_s^2} + \frac{\left( \xi_i \cdot \mathbf{u} \right) \xi_i}{c_s^4} \right] \left( \mathbf{G} + \mathbf{S} + \mathbf{S}_m \right)
$$
$$
f_i^{eq} = w_i \rho \left[ 1 + \frac{\left( \xi_i \cdot \mathbf{u} \right) \mathbf{u} : \left( \xi_i \xi_i - c_s^2 \mathbf{I} \right)}{2 c_s^4} \right]
$$

The weights $w_i$ and the discrete velocities $\xi_i$ correspond to the D3Q15 configuration (refer to Fig. 2) (Chatterjee and Chakraborty, 2005) in three-dimension as:
$$
w_i = \begin{cases} 
2/9 & (i = 0) \\
1/9 & (i = 1, \ldots, 6) \\
1/72 & (i = 7, \ldots, 14) 
\end{cases} \quad (27)
$$
$$
\xi_i = \begin{cases} 
(0, 0, 0) & (i = 0) \\
(\pm 1, 0, 0) c, \ (0, \pm 1, 0) c, \ (0, 0, \pm 1) c & (i = 1, \ldots, 6) \\
(\pm 1, \pm 1, \pm 1) c & (i = 7, \ldots, 14) 
\end{cases} \quad (28)
$$
where $c = \sqrt{3 RT}$ is the characteristic speed, and the sound speed of the model is chosen as $c_s = \sqrt{RT} = 1/\sqrt{3}.$

By using the Chapman-Enskog multiscale expansion, Eq. (24) correctly recovers the macroscopic conservation equation (Eq. 3) in the incompressible limit by setting the kinematic viscosity as
\[ \nu = c_s^2 \left( \lambda^* - 0.5 \right) \delta t, \]

where \( \lambda^* = 0.5 + \left( \lambda_f - 0.5 \right) / \rho(x,t,T) \) is the modified relaxation time for the non-isothermal flows (Chatterjee and Chakraborty, 2006) with \( \rho(x,t,T) = \sum_i f_i(x,t,T) \) being the local particle density.

In order to avoid implicitness of Eq. (24), we further introduce \( f_i^{\text{eq}} \) (He et al., 1998). Consequently, the discretized evolution equation for \( f_i \) becomes

\[
\overline{f}_i(x + \xi, \xi, t + \delta t) = \overline{f}_i(x, \xi, t) - \frac{\delta t}{\lambda + 0.5 \delta t} \left[ \overline{f}_i(x, \xi, t) - f_i^{\text{eq}}(x, \xi, t) \right] + \frac{\lambda \delta t}{\lambda + 0.5 \delta t} F_i(x, \xi, t) \tag{29}
\]

The macroscopic quantities are now obtained from \( \overline{f}_i \) as: \( \rho = \sum_i \overline{f}_i \) and \( \rho u = \sum_i \xi_i \overline{f}_i + (\delta t/2) \rho (G + S + S_M) \).

**Fig. 2.** A D3Q15 lattice configuration

### 2.4 Solution of the temperature and concentration fields

In the present study the spatial and the temporal evolutions of the temperature and concentration are solved from the supplemental energy and species transport equations (Eqs. 4 and 5), in accordance with a control volume-based fully implicit finite-difference method (Patankar 1980). The resultant discretized equation takes the following form:
\[ a_p \phi_p = \sum a_{nb}\phi_{nb} + b + a_0^p\phi_0^p - S \]  

where \( S = \frac{(\Delta H_p - \Delta H^0_p)}{\Delta t} \Delta V \) for the energy equation and 0 for the species equation. Here, \( \Delta V \) represents the volume of a computational cell (control volume) having a central nodal point \( P \), and the subscript ‘\( nb \)’ represents the neighbouring grid points. The superscript ‘0’ represents values obtained at the previous time step. The above represents a system of linear algebraic equations of the same size as the number of discrete nodes. This system is numerically solved by employing a line by line tridiagonal matrix algorithm (TDMA). For accurate prediction of the liquid fraction, the latent enthalpy content of each computational cell needs to be updated according to the predicted macroscopic value of temperature each iteration within a time step. For that purpose, an enthalpy updating scheme in accordance with the formulation of Brent et al. (1988) is used.

### 3. Results and discussion

Based on the solution scheme outlined as above, numerical simulations are performed for the laser surface alloying of aluminium on iron substrate. The thermophysical property values are taken from Chakraborty et al. (2004). The results correspond to a typical value of process parameters (\( u_s = 0.012 \) m/s, \( P = 2.4 \) kW, \( \eta = 0.15 \), \( m_f = 0.02 \) gm/s, \( r_q = 0.9 \) mm). The other parameters are set as: \( h = 15 \) W/m\(^2\)K, \( \varepsilon_r = 0.5 \), \( \sigma_{rad} = 5.669 \times 10^{-8} \) W/m\(^2\)K\(^4\), \( k_p = 0.96 \) and \( T_{\infty} = 300 \)K.

Numerical simulations are performed with a 64 x 36 x 64 (for the working domain of 8 x 4 x 8 mm\(^3\)) uniform grid system in a 15 speed cubic lattice (D3Q15). A comprehensive grid sensitivity study is also carried out. It is revealed that the percentage error with respect to the prediction of the pertinent physical parameters does not change appreciably with grid refinement, beyond a threshold mesh distribution. The lattice spacing and time step sizes are considered as per the usual LB technique, i.e., \( \delta x = \delta t = 1 \).

#### 3.1 Velocity field

The laser generated molten pool shape and size is a consequence of the convection process inside the pool. This convection is a combined effect of thermo-solutal buoyancy driven flow and the surface tension driven flow (Marangoni convection). The convection process is demonstrated through the velocity vector plots inside the molten pool. The velocity field obtained from the present simulation is shown in Fig 3. Since the surface tension coefficient of temperature is negative, a fluid element located near to the laser source will have a lower surface tension than other fluid elements located further away from the source, both fluid elements being located on the top (free) surface. This difference in surface tension induces a radially outward fluid flow on the top surface as evident from Fig 3. The forces, which influence the laser molten pool dynamics, are primarily the surface tension force, viscous force, and buoyancy force. Amongst all these forces, surface tension force is predominant and the most important one as it initiates the flow within the molten pool.
3.2 Temperature field

The top view of the temperature field is shown in Fig 4. From Fig 4, it is observed that the isotherms are more or less spherical in nature. This can be attributed by the fact that the net energy available to the pool is transported along the longitudinal and sidewise directions by the Marangoni advection due to the fluid flow, along with the thermal diffusion process. The downward advection of heat is small compared to the longitudinal and spanwise advection because of small magnitude of downward velocity component as compared to magnitudes of longitudinal and spanwise components. However, due to an enhanced mixing process the mean advection strength goes down, which results in a decrease in longitudinal and sidewise advection strength. On the other hand, an enhanced diffusion process tries to increase the dimensions of the pool in all possible directions. The resultant pool geometry is a consequence of these two counteracting effects.
3.3 Concentration field

The concentration distribution of aluminium in the molten pool is presented in Fig 5. It can be observed that the solute concentration is higher near the solidification front and gradually decreases towards the alloying front. At the alloying front, dilution of species takes place due to the addition of fresh molten base metal. On the other hand, since the solubility of the solute in the solid phase is less than that in the liquid phase, there will be preferential solute rejection from the solidified material back into the molten pool at the solidification front. The rejected solute is transported back into the centre of the pool from the solidification front by the advective effect of recirculating molten metal in the pool, along with the mass diffusion. The enhanced mass diffusivity leads to localized homogenization in the solute concentration field across the scanning direction, resulting in much flatter shapes of iso-concentration lines with negligible concentration gradients perpendicular to scanning direction. Further, the solute rejected at the solidification front diffuses towards the centre of the pool. This effect is manifested by higher penetration of iso-concentration lines near the solidification front. This has far-ranging consequences in the sense that the species concentration distribution in the vicinity of the solidification interface eventually gives rise to the final resolidified microstructure of the alloy.

3.4 Validation

In order to assess the practical validity of the present modeling effort, the hybrid LB model predictions are compared with the experimental (Mohanraj et al., 2002) and other available numerical (Chakraborty et al., 2004) results reported in the literature. The comparison is shown in Fig 6. The figure shows the interface composition of the solidified layer along the depth of the pool. A satisfactorily good agreement is observed between the hybrid LB and the experimental as well as the continuum based numerical results.
4. Conclusions

A hybrid LB model is presented to simulate the transport processes occurring in high energy materials processing applications. The hydrodynamics is monitored by the conventional LB approach, while the thermal and compositional behaviors are predicted through solution of auxiliary scalar transport equations. Additionally, the model includes the macroscopic phase changing aspects in an elegant and straightforward manner into the LB equation. A high power laser surface alloying process is simulated using the developed method. The hydrodynamic, thermal and compositional characteristics obtained from the present simulation are in reasonably satisfactory agreement with the available experimental and continuum based numerical simulation results. Because of its inherent simplicity in implementation, stability, accuracy, as well as its parallel nature, the proposed hybrid LB model may turn out to be a potentially powerful tool for solving numerically complex phase change problems commonly encountered in engineering and physics, characterized by complicated interfacial topologies.

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