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AN INVESTIGATION OF MOLTEN MICRODROPLET SURFACE DEPOSITION: TRANSIENT BEHAVIOR, WETTING ANGLE DYNAMICS AND SUBSTRATE MELTING PHENOMENON

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Summary

This thesis investigates key aspects of the fluid dynamics, heat transfer and phase change occurring during the deposition of a molten metal droplet on a colder substrate. These aspects, important to novel technologies like microelectronics packaging and micromanufacturing, have been examined experimentally, theoretically and numerically. The experimental study in Chapter 2 focused on the complex transient aspects of the droplet impact, spreading and solidification process, which have been examined through recent numerical studies. A strobe microscopy technique was developed and used. In a first series of experiments, the value of the initial substrate temperature was varied in order to study its influence on the spreading and solidification process. The dynamic interaction between the oscillation in the liquid region and the rapid advance of the solidification front was visualized and quantified. Transient measurements of the droplet height above the substrate have shown a damped oscillation. These results suggest that the solidification time depends nonmonotonically on the substrate temperature. It was also shown that the ripples on the frozen drop surface are due to a strong coupling between solidification and flow oscillations, as suggested by recent numerical results. In a second series of experiments, the evolution of the wetting angle between the spreading drop and the substrate was recorded and analyzed. The influence of the initial impact velocity and substrate temperature on the dynamics of the measured wetting angle was described. Two regimes were identified and no quantitative agreement with the widely used Hoffman's correlation for wetting was found. It was established that the wetting angle dynamics is strongly coupled with the evolution of the droplet free surface.

Chapter 3 presents a numerical investigation of molten microdroplet impact, spreading and solidification on a colder flat substrate which can melt due to the energy input from the impacting molten material. The numerical model is based on the axisymmetric Lagrangian Finite-Element formulation of the Navier-Stokes, energy and material transport equations. The model accounts for a host of complex thermofluidic phenomena, exemplified by surface tension effects and heat transfer with phase change in a severely deforming domain. The dependence of the molten substrate volume on time was determined and discussed. The influence of the thermal and hydrodynamic initial conditions on the amount of substrate melting is discussed for a range of superheat, Biot and Reynolds numbers. Multidimensional heat transfer effects, as well as material mixing between the droplet and the substrate are found and quantified. The underlying physics is discussed. Good agreement in the main features of the maximum melting depth boundary between the present numerical results and published experiments of other investigators for larger (mm-size) droplets was obtained. A complex mechanism was identified, showing the influence of the droplet fluid dynamics, particularly the free surface motion and convection heat transfer, on the substrate melt-

ing and resolidification.

In Chapter 4, a good agreement has been obtained between experimental results obtained in Chapter 2 and results of the numerical modeling presented in Chapter 3 (without substrate melting). Such matching technique shows promise to quantify physical parameters like surface tension, and mesoscopic phenomena like heat transfer through interfaces.