In general, the additive manufacturing system can include a platen to receive feed material, a feed material dispenser, one or more heat sources that can heat the deposited feed materials, and a coolant dispenser to dispense coolant fluid onto the deposited feed material. The heat sources can include a beam source, a heat lamp array, and/or resistive heater coils that are embedded in the platen. Components of the feed material dispenser, the beam from the beam source, and the coolant dispenser can move relative to one another or in conjunction with one another (i.e., are fixed relative to each other in operation) as they traverse across the platen to deposit, fuse and cool, respectively, the feed material.

FIGS. 1A and 1B are side views of implementations of an additive manufacturing system 100. The additive manufacturing system 100 includes a support 102 to hold the object being fabricated, a feed material delivery system to deliver a layer of feed material over the support 102, a first heat source 155, such as an array of heat lamps, configured to heat the entire layer of feed material, a second heat source 160 configured to generate a beam 175 to scan across the layer of feed material and selectively heat portions of the layer of feed material sufficiently to fuse the feed material, and coolant dispensers 145 and 146 (see FIG. 1B) to control the temperature of the feed material deposited over the support 102.

Optionally, some parts of the additive manufacturing system 100 can be enclosed by a housing 110. The housing 110 can, for example, allow a vacuum environment to be maintained in a chamber 112 inside the housing, e.g., pressures at about 1 Torr or below. Alternatively the interior of the chamber 112 can be a substantially pure gas, e.g., a gas that has been filtered to remove particulates, or the chamber can be vented to atmosphere.

The support 102 can include a platen 105 that is vertically movable, e.g., by a linear actuator 107a that is connected to the platen 105. In addition, the support can include a heater, such as a resistive heater embedded in the platen 105 or a lower lamp array 109a below the platen, to heat the platen and the feed material 130 that has been deposited on the platen 105.

The feed material delivery system delivers the feed material from a reservoir to the platen. For example, in the case of a powder, the feed delivery system can dispense a layer of powder across the support, where the powder will be fused. In some

temperature, additional energy sources, e.g., the second heat source 160, is used to heat the feed material to the sintering temperature.

The second heat source 160 can be, for example, a laser to generate a laser beam 175. Alternatively, the second heat source 160 can be an electron source to generate an electron beam 175. The beam 175 can scan over the layer of feed material, the power of the beam can be modulated to selectively fuse, e.g., sinter, portions of the layer of feed material.

The second heat source 160 includes a beam source 170 (that produces a beam 175), an actuation system 165, and an optical system 167. The beam 175 can, for example, be a laser beam or an electron beam. The actuation system 165 can translate the beam 175 in the x-y plane to scan the top surface of the feed material. For example, the actuation system 165 can include a galvo-controlled mirror to deflect the laser beam at a desired angle, or the actuation system 165 can include an actuator that moves the beam source 170 relative to the platen 105.

In some implementations, the actuation system 165 can be configured to translate the beam source 170 in the Z direction which can allow the control of the shape of the spot size of the beam 175 on the top layer of the feed material. The optical components 167 can also control the depth of focus and/or the spot size of the laser beam 175 on the top surface of the feed material.

Throughput of the system 100, can be increased by applying several techniques. For example, as described above, feed material 130 in the reservoir can be heated from the room temperature to the “free flowing temperature” by a combination of heat source 135, resistive heater embedded in the support plate 122 and a lower lamp array 126. Heating the feed material prior to deposition onto the platen 105 can help reduce the time needed to fuse the deposited feed material.

Throughput of the system 100, can also be increased by having two reservoirs 120a and 120b positioned on opposite sides of the platen which allow feed material to be alternately dispensed. For example, the spreader 140 can be moved in a first direction from the reservoir 120a at the left end of the platen 105 to the reservoir 120b at the right end of the platen 105, and in the process spreading a layer of the feed material 130 from the reservoir 120a over the platen 105. After that layer has been processed, another layer

of feed material can be dispensed by moving the spreader 140 in an opposite second direction from the reservoir 120b to the reservoir 120a, and in the process spreading another layer of feed material.

Throughput of the system 100 can also be increased by having a coolant dispenser to regulate the temperature of the feed material 130 deposited on the platen 105. For example, after a layer of feed material has been deposited and fused, it may be desirable to cool the fused feed material before processing the next layer of feed material. Cooling the feed material prevents the heat from the fused feed material from changing the temperature of the surrounding feed material. This can, for example, reduce accidental sintering or melting of the next layer of feed material. This can also, for example, reduce the spatial temperature fluctuations across and between the layers of deposited feed material, and thus reduce thermal stress and thereby improve material properties. The coolant dispenser can, for example, be an air knife that dispenses air or some other gas, e.g., nitrogen.

The spreader 140 and the coolant dispenser 145 can be coupled to or mounted on one or more drive mechanisms (for example actuators) that can be controlled by one or more controllers (for example, controller 190). Thus, the roller 140 and the coolant dispenser 145 can move relative to the platen, e.g., scan along the length of the platen (in the y-direction). The spreader 140 and the coolant dispenser 145 can be mounted on separate actuators which can allows them to move relative to each other and relative to the beam 175.

The spreader 140 and the coolant dispenser 145 can move relative to or in conjunction with the beam 175. In some implementations, the spreader 140, dispenser 145 and beam 175 scan across the platen 105 in a scanning direction, e.g., left to right. In some implementations, the spreader 140, coolant dispenser 145 and beam 175 move relative to the platen 105 but in conjunction with one another such that the spreader 140 is ahead of the coolant dispenser 145 (in the direction of motion of the spreader 140, dispenser 145 and beam 175) while the beam 175 sinters the feed material between the two.

The dispenser 145 can include a conduit that can simultaneously dispense coolant fluid across the width of the platen (along x direction). The conduit can have a contiguous slot or multiple apertures that are spaced apart and extend over the width of the platen.

FIG. 2A illustrates an implementation of a dispenser 145 that includes a conduit 185 coupled to an actuator 181. The conduit 185 can have a contiguous slot 182 and is coupled to a coolant fluid source 186 via connector 184, e.g., flexible tubing.

FIG. 2B illustrates an implementation of a dispenser 145 in which the conduit 185 has multiple apertures 183. The conduit and apertures 183 are coupled to a coolant fluid source 186 via a common connector 184, e.g., flexible tubing.

As shown in FIG. 2C, the additive manufacturing system 100 can also have more than one coolant dispenser, e.g., dispensers 145 and 146. The dispensers can extend in parallel across the platen 105.

The coolant fluid can be a gas, e.g., air or nitrogen. In some implementations the fluid can be a liquid, e.g., a fast-evaporating liquid such as isopropyl alcohol. The fluid can be refrigerated, e.g., below room temperature, before being dispensed.

Depending on the dispensing mechanism and control of the fluid flow, the coolant fluid emerges continuously or intermittently from the slot or the aperture in the conduit onto the feed material. The rate of flow of the coolant fluid through the contiguous slot or apertures can also be adjusted by controlling the pressure of the coolant fluid with a pressure regulator 188 that is controlled by a controller 190. Alternatively, the flow rate of the coolant fluid can be controlled by a pump (not shown). Control of the temperature and flow rate of coolant fluid can allow control over the rate of cooling of the feed material. The coolant fluid dispenser is configured to deliver coolant fluid at a temperature and mass flow rate sufficient to ensure that accidental fusing of the subsequently deposited layer does not occur.

However, the flow rate of coolant fluid should be low enough that powder in the layer that was not fused is not significantly disturbed. For example, the flow rate can be selected to avoid blowing the unfused powder across other areas of the platen.

The coolant dispenser 145 can be coupled to an actuator that can move the dispenser toward and away from the platen 105. This can, for example, serve as a control

to regulate the cooling of the feed material, and provide greater flexibility in arranging the various components of the additive manufacturing system 100.

FIG. 1A illustrates a coolant dispenser 145 that can dispense coolant onto the feed material deposited on the platen 105. The coolant dispenser 145 extends along and across the width of the platen 105 (in the x direction). Further, the system 145 is mounted or attached to an actuator 181 (see FIG. 2A-2C) that allows it to traverse the length of the platen 105 (along y direction). The actuator 181 can also be configured to move the coolant dispenser 145 in the vertical z direction.

In the embodiment shown in FIG. 1A, the roller moves from left to right depositing a layer of feed material on the platen. The desired portions of the layer of feed material is fused by the beam 175 which scans over the layer. Then, the coolant dispenser 145 traverses the platen.

The relative motion of the spreader 140, the beam 175 and the coolant dispenser 145 can be controlled by one or more controllers 190. The coolant dispenser 145 can, for example, begin traversing the platen 105 before the beam 175 has finished scanning over the layer of feed material. In other words, the coolant dispenser 145 can follow the beam 175 as the latter traverses across the platen. Alternatively, the coolant dispenser 145 can begin traversing over the platen 105 after the beam 175 has traversed across the platen 105 and heating of the entire layer of feed material is completed.

Once the spreader 140 and the coolant dispenser 145 (and beam source if it is movable) have scanned along the platen 105, then can be returned to the starting side to begin processing of another layer.

FIG. 1B is another implementation of the additive manufacturing system that contains two coolant dispensers 145 and 146 that are arranged along the width of the platen (x direction), and can traverse the length of the platen (along y direction). The two dispensers are mounted on separate actuators and controlled by one or more controllers 190. The motion of the two coolant dispensers over the platen can be configured in several ways.

As one example, once the entire layer of feed material has been deposited and fused by the spreader 140 and the beam 175, respectively, the coolant dispensers 145 and 146 can simultaneously begin traversing from left to right and right to left, respectively.

have multiple opening that extends across the width of the platen (x direction). In this case, in operation, the dispensers 104a, 104b can scan across the platen 220 in a single sweep in the direction 206 (along y axis).In another embodiment, each dispenser can have a single opening. In this case, the dispensers 104a, 104b can scan both along the breadth and length of the platen 220 (along the x and y direction, respectively), e.g., a raster scan across the platen 220. In both the aforementioned embodiments, each opening can have an independently controllable gate, so that delivery of the feed material through each opening can be independently controlled.

During manufacturing, layers of feed materials are progressively deposited and fused, e.g., sintered or melted. For example, the first and second feed materials 114a and 114b are dispensed from the material dispenser 104 to form a first layer. The second feed material 114b can have a higher sintering or melting point than the first feed material 114a. If the layer of feed material comprising both feed materials is heated to a temperature above the sintering temperature of the first feed material but below that of the second feed material, the deposited cluster of first feed material 114a can fuse together whereas the second feed material 114b remains in loose (i.e., powder) form.

The system 200 includes a heat source 234 configured to raise the temperature of an entire deposited layer simultaneously. For example, the heat source 234 can be a two-dimensional array of heater lamps 236. As illustrated in Fig. 2 the heat source 234 can be positioned above the platen, i.e., on the same side of the platen 220 on which the feed material is deposited, and spaced away sufficiently from the platen 220 so that the dispensers 104a and 104b, and the coolant dispenser 145 can pass between the platen 220 and the heat source 234.

The platen 220 can also be heated by another heat source, for example, an embedded heater 226, to a base temperature that is below the melting points of both the first and second feed materials. The heat source 234 is triggered to impart sufficient energy to melt the first feed material without melting the second feed material. In this way, the heat source 234 can be configured to provide a smaller temperature increase to the deposited material to selectively melt the first feed material. Transitioning through a small temperature difference can enable each deposited layer of feed materials to be processed more quickly. For example, the base temperature of the platen 220 can be

about 1500 °C and the heater source 234 can be triggered to impart energy to cause a temperature increase of about 50 °C.

Alternatively, the heat source 234 could be used to heat the platen 220 to the base temperature, and the embedded heater 226 could be triggered to impart sufficient energy to melt the first feed material without melting the second feed material. The platen 220 can include side walls 222 and 224 that are each heated by heaters 228 and 230, respectively.

As shown in FIG. 3, the material dispenser 104 traverses the length of the platen (along the y direction, e.g., from left to right) depositing a layer of feed material that comprises the first and the second feed material. The heat source 234 can be triggered after a layer has been deposited by the material dispenser 104. The deposited layer of feed material is heated by the heat source 234 for a duration of time needed to impart sufficient energy to fuse the first feed material, without fusing the second feed material. Then the heat source 234 is switched off and the coolant dispenser 145 traverses from left to right dispensing coolant fluid onto the layer of feed material.

The coolant dispenser 145 can include a conduit to simultaneously dispense coolant fluid across the width of the platen through a contiguous slot or through multiple apertures arranged along the width of the platen. A coolant fluid emerges continuously or intermittently from the slot or the aperture onto the feed material. The rate of flow of the coolant fluid can also be adjusted by controlling the size of the slots and apertures by a controller 190. The process of deposition, fusing and cooling of feed material is repeated as the dispenser 104 and the coolant dispenser 145 traverse from right to left.

The material dispenser 104 and the coolant dispenser 145 can be mounted on separate drive mechanisms (for example, actuators) that are controlled by one or more controllers 190. This configuration can allow the assembly 104 and the coolant dispenser 145 to move relative to one another. In one embodiment, the coolant dispenser 145 can traverse the length of the platen several times dispensing coolant onto a layer of feed material until a desired temperature distribution is achieved. For example, it may be desirable to cool the layer of deposited feed material until the temperature of the entire or a part of the layer falls below the sintering temperature of both the first and the second feed material.

FIG. 4 illustrates an implementation of an additive manufacturing system 300 that includes a material dispenser 104 and a platen 105, held by a support 102, to receive the feed material. The material dispenser can traverse the length and breadth of the platen 105 depositing feed materials 114a and 114b that sinter/melt at different temperatures. The support 102 comprises a lower lamp array 109 to heat the platen and a piston 107 to move the platen 105 in the vertical direction. The system can also have a second heat source 160 configured to generate a beam 175 to scan over the layer of feed material deposited on the platen 105. The heat source 160 includes a beam source 170, an actuation system 165, and an optical system 167. The system 300 also includes a coolant dispenser 145 to dispense coolant fluid onto the feed material deposited on the platen 105.

The first and second feed materials 114a and 114b can have different sintering temperatures. For example, the first feed material can have a lower sintering temperature. In one embodiment, the lower lamp array heats the deposited layer of feed material to a temperature that is below the sintering temperatures of both the first and the second feed materials. Then, the beam 175 from the beam source 170 scans over the layer of deposited feed material providing the incremental energy needed to sinter the first feed material.

The dispenser 145 can include a conduit that can simultaneously dispense coolant fluid across the width of the platen (along x direction). The conduit can have a contiguous slot or multiple apertures that are spaced apart and extend over the width of the platen. A coolant fluid emerges continuously or intermittently from the slot or the aperture onto the feed material.

The material dispenser 104 and the coolant dispenser 145 can be coupled to or mounted on one or more drive mechanisms (for example actuators) that can be controlled by one or more controllers 190. Further, the material dispenser 104 and the coolant dispenser 145can move relative to or in conjunction with the beam 175. For example, the material dispenser 104 and the coolant dispenser 145 can be mounted on separate actuators which can allows them to move relative to each other and relative to the beam. In other implementations, the material dispenser 104 and the coolant dispenser 145 do not

move relative to each other: the assembly 104 is ahead of the coolant dispenser 145 while the beam 175 sinters the feed material between the two.

In some implementations, the coolant dispenser 145 traverses over the platen 105 after the beam 175 has finished scanning over the entire layer of deposited feed material. For example, once a new layer of feed material that includes the first and the second material has been deposited, the beam 175 can scan from left to right sintering the desired portions of the deposited layer. After the beam 175 has completed scanning over the entire surface, the coolant dispenser 145 can traverse from left to right dispensing coolant over the layer of feed material.

The coolant dispenser 145 can be configured to traverse over the entire layer or a part of the layer of deposited feed material. For example, a sensor can monitor the temperature of the surface of the deposited feed material and a control system can regulate the path of the coolant dispenser based on the signal from the sensor. The path of the coolant dispenser can include traversing over the entire layer of deposited feed material several times until a desired temperature distribution is achieved. The control system can also regulate the rate of flow of coolant fluid from the coolant dispenser.

FIG. 5 illustrates an implementation of an additive manufacturing system that includes a platen 105 (supported by a support 102) that can receive feed materials from a material dispenser 104. The dispenser assembly 104 can traverse across the platen and deposit a first feed material 114a or a second feed material 114b at desired locations on the platen. The feed materials 114a and 114b have different sintering temperatures. The support 102 comprises a lower lamp array 109 to heat the platen and a piston 107 to move the platen 105 in the vertical direction. The system can also have a second heat source 430 that extends across the width of the platen (along x direction). The heat source 430 includes a linear array of heat lamps 435 and can traverse across the platen (along y direction).

The system 400 also includes a coolant dispenser 145 that can include a conduit that can simultaneously dispense coolant fluid across the width of the platen (along x direction). The conduit can have a contiguous slot or multiple apertures that are spaced apart. A coolant fluid emerges continuously or in bursts from the slot or the aperture

For any of the systems described, the coolant dispenser can be configured to dispense coolant fluid over desired portions of the feed material rather than the entire layer of deposited feed material. Heating and cooling of desired portions of the deposited feed material can provide better control of the additive manufacturing process. For example fluctuation of temperatures experienced by particular regions of the deposited feed material can be controlled. This can improve the quality of the additive manufacturing process.

A number of implementations have been described. However, certain features can be combined for advantageous affect, without including other features. For example, the following combinations are possible:

- The coolant dispenser can traverses over the length of the platen dispensing coolant fluid before the deposition (and fusing) of a layer of feed material. This is done to control the temperature of the previously deposited layer of feed material.
- The coolant dispenser can dispense coolant fluid over the length of the platen several times until a desired temperature of the deposited feed material is achieved.
- The additive manufacturing system can have multiple coolant dispensers configured to cool the deposited feed material.
- The temperature of the entire layer of the feed material can be raised to the free flowing temperature before the feed material is dispensed, and then the temperature of the layer of feed material can then be selectively increased to the fusing temperature, without raising all of the layer of feed material to the caking temperature. In this case, the first heat source can be optional.
- The temperature of the entire layer of the feed material on the platen can be raised to the caking temperature without deliberately raising the temperature of the feed material before it is dispensed. In this case, the heater for the reservoir can be optional.
- The lamp array surrounding the second heat source can be used to raise the temperature of the feed material, but not above the caking temperature.
- The lamp array surrounding the second heat source can remain stationary rather than rotating.