Control Chip Temperature During VLSI Device Burn-in

Harold Hamilton - April 01, 1999
High-power VLSI devices exhibit a wide disparity in heat dissipation. Variations in semiconductor fabrication processes contribute to differing rates of dissipation among devices with identical pin numbers operating under identical conditions. Such devices can exhibit as much as 50% variation in heat dissipation during burn-in. Moreover, varying test conditions (such as frequency) contribute to power-dissipation variations within a single part. To compensate for these power-dissipation variations, you can provide independent temperature regulation for individual devices during burn-in. Such regulation keeps you from damaging good parts with high dissipation and assures that you adequately stress devices having inherently low dissipation.

The traditional bathtub curve (Fig. 1) represents semiconductor device failure rates as a function of time. The initial failure rate is high, but devices that survive the first few hours—the infant-mortality period—operate reliably until they reach the end of their useful lives.

Burn-in Strategies

Burn-in strategies include static, dynamic, and burn-in with heat. Static burn-in systems apply extremes of voltage and temperature to each device but do not exercise the device. Thus, static burn-in to the longest expected life of the burn-in strategies does not stress all the potential failure mechanisms. Dynamic burn-in systems exercise the device inputs and outputs and temporarily stress the outputs in addition to applying extremes of voltage and temperature. With dynamic systems, electron charge transfers occurring at the exercised device's circuit nodes initiate failure mechanisms that would escape static burn-in.

Burn-in with test systems test devices while stressing them. They provide test vectors to a device and compare actual device outputs with expected outputs while the device under test (DUT) operates at its voltage and temperature limits. Burn-in with test systems can identify devices that fail to meet open-circuit conditions but that would pass a pin burn-in in more-restrictive test.

Burn-in with test systems also verify that a device under test gets exercised—that is, the device is powered up and test vectors are applied. Keep in mind that burn-in sockets—fragile high-pin-count components subjected to repeated insert/remove action cycles of production burn-in—wear themselves into failure. Just a few bad socket pins could prevent test vectors or supply voltages from reaching the device undergoing burn-in, resulting in your skipping or snagging parts that haven't been electrically stressed.

In one approach to high-power burn-in, an operator plugs devices into sockets on one side of a burn-in board (Fig. 2). A dedicated or other press fixture then brings a heat-sink assembly (Fig. 3) into contact with each device.

A high-power burn-in system's software can provide individual device temperature control and monitoring. In the example, the display provides color-coded information about each device; text codes provide details. The display also shows global temperature settings for the burn-in board as well as actual minimum, maximum, and average temperatures and heater duty cycles. 7280W

Figure 1. The traditional bathtub curve describes silicon device failure rates with respect to time. Devices that survive the first few hours will likely last years.

The burn-in process uses power and temperature extremes to compress the infant-mortality period, forcing failures to occur quickly, thus saving time and money. The more extreme the power and temperature, the sooner failures occur in the burn-in process; the associated burn-in time is the required burn-in time. Ultimately, increasing voltage and temperature will not only compress the infant-mortality period but also weaken good devices that will survive the burn-in yet fail well before their anticipated end of life.

The total heat dissipation of the heat-sink assembly is nearly constant as the power dissipation of the device varies under test. Thus, the air temperature and velocity, once appropriately set, need not be changed during testing. The total heat dissipation of the heat-sink assembly is a function of the device power and the thermal characteristics of the heat-sink assembly.

The heat-sink assembly contains a spring, temperature sensor, and heater. The spring holds the temperature sensor tightly against the device package to ensure good thermal contact. The control circuitry monitors the device temperature and applies the proper heater power to maintain the required temperature.

Maintaining Die Temperature

The die inside the DUT is the active component whose temperature is most important. The high power burn-in system monitors and controls the package temperature, which is in turn controls the die temperature in accordance with the thermal impedance between the die and the package. The thermal impedance isn't typically less than 0.5°C/W, depending on package, die, and die-attachment method. Although this thermal impedance varies by device type, it's usually uniform for a given part.

You can calculate the package temperature (TP) required to maintain a specific die temperature (TD) from the thermal impedance (Z) and the DUT heat dissipation (P):  

\[ T_P = T_D - (Z \times P) \]

For example, the package temperature required to provide a die temperature of 150°C for a device with the thermal impedance equal to 0.25°C/W and a heat dissipation of 10 W is as follows:

\[ T_P = 150°C - (0.25°C/W \times 10W) = 147.5°C \]

Thus, controlling the package temperature to 147.5°C will maintain the die temperature at 150°C at 10-W dissipation.

Air Temperature and Velocity

A high-power burn-in system accommodates multiple burn-in boards heat-sink-assembly combinations and provides an airflow coiler. The optimum air temperature and velocity are functions of device power, the thermal characteristics of the heat-sink assembly, and the required package temperature.

The quantity of heat transferred to the air is inversely proportional to the air temperature and the air velocity. High-power burn-in systems provide air temperature and velocity at the device to maintain the die temperature at 147.5°C, which is the thermal impedance of the heat-sink assembly and the required package temperature. The heat-sink assembly transfers the heat dissipated from the device to the air at the air-stream temperature, TD, which is the thermal impedance of the heat-sink assembly.

To determine the optimal air-stream temperature, TD, for a 10-W device with a thermal impedance of 0.25°C/W, you can use the following equation:

\[ TD = T_P - (Z \times P) \]

For example, the package temperature required to provide a die temperature of 150°C for a device with the thermal impedance equal to 0.25°C/W and a heat dissipation of 10 W is as follows:

\[ TD = 150°C - (0.25°C/W \times 10W) = 147.5°C \]

Thus, controlling the package temperature to 147.5°C will maintain the die temperature at 150°C at 10-W dissipation.

Air temperature and velocity are generally set so that the heater runs at half power (50% duty cycle) when the device is operating at nominal power. This choice centers the heater output relative to the device power range. As the heat grows off the device increases, the control circuitry senses the temperature increase and reduces the heater power, allowing the package temperature to settle back to the setpoint temperature. Similarly, as the device dissipates less heat, the heater will dissipate more.

The total heat dissipation of the heat-sink assembly is nearly constant as the power dissipation of the device varies under test. Thus, the air temperature and velocity, once appropriately set, need not be changed during testing. This is true as long as there is no change in the device power or radiation variations in the air temperature and velocity. Although this is true at steady state, the heater power can more than double during testing due to the increased air-stream temperature, which is needed to maintain the required package temperature. This increase in heater power is more than offset by the increase in heater efficiency, which is inversely proportional to the air-stream temperature.

Central Systems

A high-power burn-in system's software can provide individual device temperature control and monitoring. In the example, the display provides color-coded information about each device; text codes provide details. The display also shows global temperature settings for the burn-in board as well as actual minimum, maximum, and average temperatures and heater duty cycles. 7280W

Figure 2. The burn-in board accommodates 24 DUTs. A burn-in-board test strategy ensures that supply voltages and test vectors pass through the fragile burn-in-board sockets to the DUT.

Figure 3. A heat-sink assembly attaches to each DUT on a burn-in board. A sensor provides temperature information to a control subsystem, which regulates device temperature by controlling heater duty cycle. Thermal flows ensure good thermal contact between DUT and heat-sink assembly.

Figure 4. Many combinations of air temperature and velocity will remove a given amount of heat. Each of the three lines here represents the various combinations of air temperature and velocity that will provide the required heat flow from a heat-sink assembly.

Air temperature and velocity are generally set so that the heater runs at half power (50% duty cycle) when the device is operating at nominal power. This choice centers the heater output relative to the device power range. As the heat grows off the device increases, the control circuitry senses the temperature increase and reduces the heater power, allowing the package temperature to settle back to the setpoint temperature. Similarly, as the device dissipates less heat, the heater will dissipate more.

The total heat dissipation of the heat-sink assembly is nearly constant as the power dissipation of the device varies under test. Thus, the air temperature and velocity, once appropriately set, need not be changed during testing. This is true as long as there is no change in the device power or radiation variations in the air temperature and velocity. Although this is true at steady state, the heater power can more than double during testing due to the increased air-stream temperature, which is needed to maintain the required package temperature. This increase in heater power is more than offset by the increase in heater efficiency, which is inversely proportional to the air-stream temperature.

Central Systems

A high-power burn-in system's software can provide individual device temperature control and monitoring. In the example, the display provides color-coded information about each device; text codes provide details. The display also shows global temperature settings for the burn-in board as well as actual minimum, maximum, and average temperatures and heater duty cycles. 7280W