Phase Diagrams & Pb-free Low-temperature Solder Materials in Microelectronics

Background

1. Electronic packaging and solder materials

In the field of microelectronics, computer chips and other components are attached to printed circuit boards (PCBs) using **solder**. A good solder material should perform two important functions: it should carry electrical signals and it should form a strong mechanical bond between the components and the circuit board (think about being able to withstanding dropping your cell phone!) **Low melting point metal alloys** are a class of material that can perform these functions. These alloys are typically composed of tin (Sn) combined with other metals that are selected to tailor the melting point for the specific conditions under which the electronics will be used. Solder materials are an essential component in all products that contain computer chips and circuit boards. Figure 1 shows examples of circuit boards and solder paste.

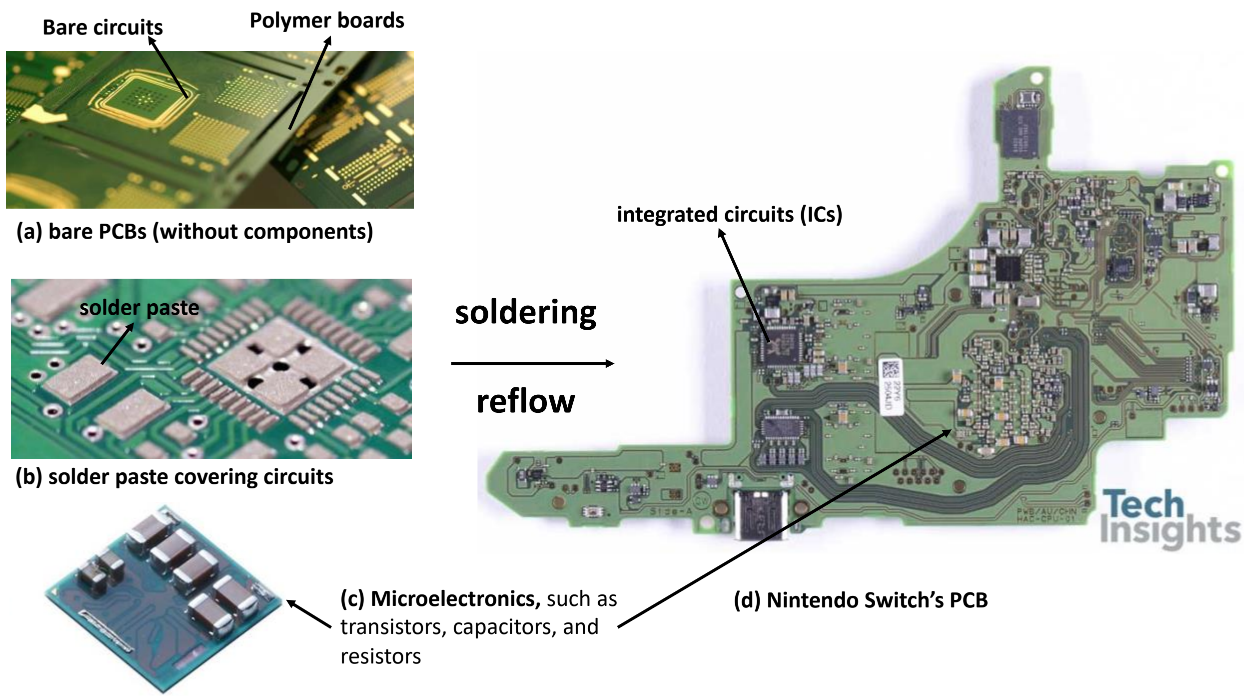

Figure 1: The procedure of assembling a Nintendo Switch's printed circuit board (PCB). Figure credit: https://www.techinsights.com/blog/nintendo-switch-teardown

2. Lead (Pb)-free solders and sustainability

Sn-Pb alloys (usually the Sn-Pb eutectic composition) were used for decades as the primary solder material in the electronic industry. Unfortunately, Pb is a toxic element that has harmful effects on human health and the environment. With the implementation of legislation prohibiting the use of Sn-Pb solder in consumer electronic products starting in 2003, most commercial electronics have moved to using Pb-free alloys. The exceptions have been for military and aerospace systems that require high reliability in extreme environments. Common Pb-free solders include the Sn-Ag-Cu alloy (SAC) and Sn-Bi alloy.

3. Reflow soldering and low-temperature solders

Reflow soldering is a manufacturing process that forms permanent, reliable joints between components and the circuit board. In the reflow process, solder paste is applied to bare PCBs through a stencil whose holes align copper areas on the board with connections on the computer chips. Once the solder is stenciled onto the board, the components are placed onto the circuit board in alignment with where the paste was stenciled. The circuit board with its components and paste is then heated to a temperature that is high enough to melt the solder but low enough that the polymer part of the circuit board does not burn. To visualize this manufacturing process, imagine the circuit board traveling on a conveyor belt through a long oven, a little like a pizza oven, moving from one temperature zone to the next. The first temperature zone will melt the solder, and then the entire circuit board moves through another temperature zone where the solder will cool and solidify.

Recently, manufacturers have been motivated to use low temperature solders to reduce manufacturing and assembly costs. The Sn-Bi solder is one of the promising Pb-free solder materials that meets the requirements of having a low melting point, low cost and low environmental impact.

Problem Set

1. Plot and analyze two binary phase diagrams using Thermo-Calc

Plot the Sn-Pb and Sn-Bi binary phase diagrams using the Thermo-Calc tool on nanoHUB.org:

- https://nanohub.org/tools/tcacademic

Learn about Thermo-Calc and find step-by-step directions here:

- https://nanohub.org/resources/36098

After plotting the two phase diagrams, in each figure label the following:

- the phase(s) in each region, including the two-phase regions
- the eutectic temperatures and compositions
- the melting temperatures of pure Sn, Pb, and Bi

2. Apply the lever rule

Select and mark a point in a two-phase region in the Sn-Bi phase diagram. Show how the phase fraction at this point can be calculated by hand using the lever rule, and compare these results with the values returned by Thermo-Calc. Use units of weight% (wt%) and °C.

3. Identify the correct reflow profile

In a reflow oven, a circuit board is slowly heated up to the temperature where the solder melts. A **reflow profile** is the temperature-time process needed for a specific circuit board. Please watch this video about surface mounting technology (https://www.youtube.com/watch?v=u0chrqzf8Hg to help you understand the manufacturing procedure and solve this problem.

There are typically two types of reflow profile, as shown in Fig. 2. One has a heating rate that changes over time, and the other has a constant heating rate. The maximum temperature, referred to as the **peak temperature**, is usually 40 °C above the solder's melting temperature.

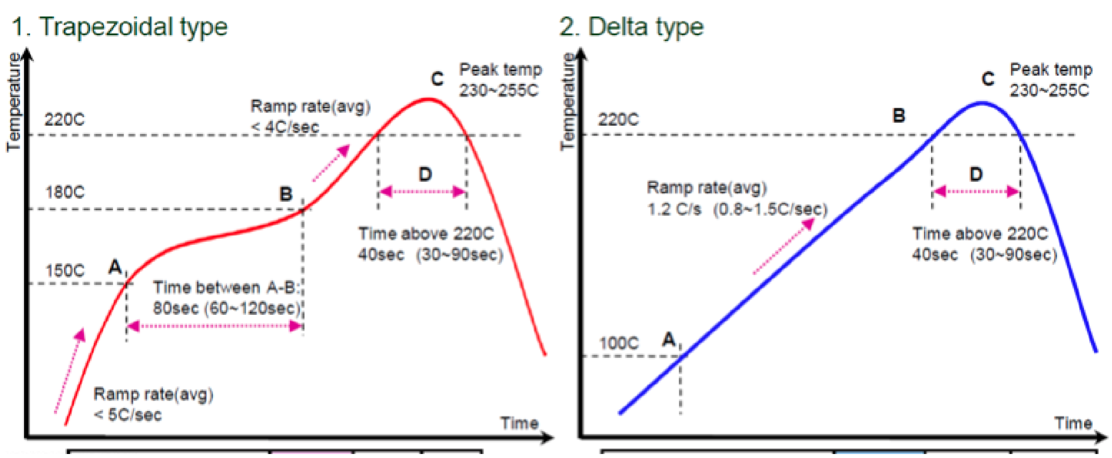

Figure 2: Two typical reflow profiles

Figure credit: https://www.7pcb.com/blog/lead-free-reflow-profile.php

Figure 3 shows two reflow profiles: one for Sn-Pb solder and the other for Sn-Bi solder. Using the information provided in the background video, please match the correct profile to the correct alloy, and justify your answer.

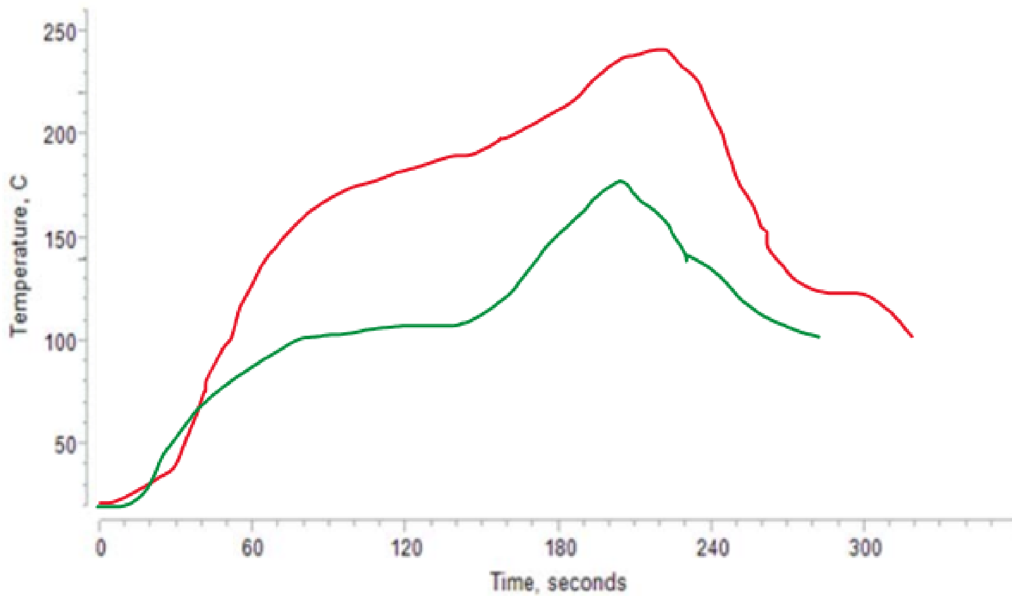

Figure 3: Two reflow profiles to be identified.

4. Identify the liquidus line for a given composition

Your team is given three types of Sn-Bi solder paste containing 20%wt, 40%wt, and 60%wt Bi, and your task is to design a reflow operation for each of these solders. What is the minimum temperature that each solder paste needs to reach for melting to occur? (The **Reflow zone** refers to the stage where solder paste is above the liquidus.)

5. Design a delta-type reflow profile

You are to design a simple reflow profile for a Sn-Bi eutectic solder. Assume that in your delta-type reflow profile, the heating rate is constant at 1.2^{o}C /sec until the peak temperature is reached, and the cooling rate is constant at 4^{o} C/sec dropping from the peak temperature to room temperature. (We already know from question 3 that the peak temperature is about 40^{o}C over melting temperature.) Please plot the reflow profile.

6. Reflections

(1) In your own words please give an example of what materials properties matter in microelectronics and explain why.

(2) Please summarize how phase diagrams can guide materials design and manufacturing in the microelectronics industry.