In situ study of eutectic tin-bismuth electromigration

Prabjit Singh
IBM Corporation
+1-845-489-4349,
pjsingh@us.ibm.com

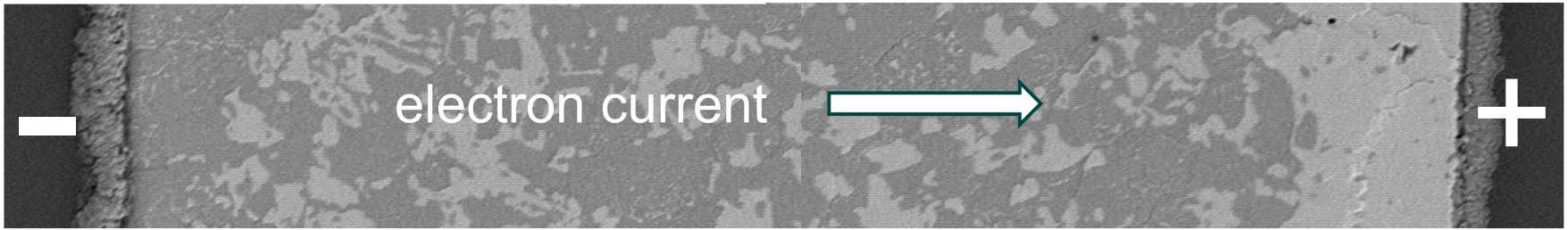
Co-author list

Name	*Company*
Larry Palmer	*IBM*
Mehdi Hamid	
Tom Wassick	
Eric Campbell	
Raiyo Aspandiar	*Intel Corporation*
Brian Franco	

Name	*Company*
Richard Coyle	*Nokia*
Faramarz Hadian	
Vasu Vasudevan	*Dell*
Aileen Allen	*HP, Inc*
Keith Howell	*Nihon Superior*
Kei Murayama	*Shinko*

Name	*Company*
Hongwen Zhang	*Indium Corporation*
Anna Lifton	*MacDermid Alpha, Electronic Solutions*
Murali Sarangapani	*Heraeus Materials*
Terry Munson	*Foresite, Inc*
Steven Middleton	
Haley Fu	*iNEMI*

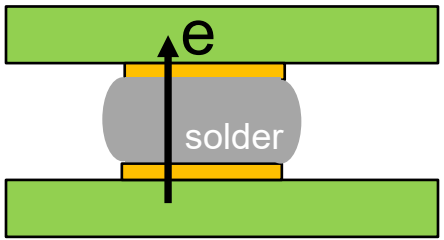
Electromigration in tin-bismuth (Sn-Bi) alloys



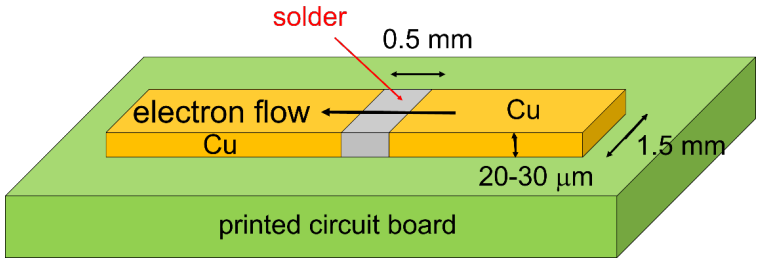
Electrons have mass and velocity and therefore momentum.
Newton said momentum is conserved when objects collide.
Electrons collide with and transfer momentum to atoms, preferentially Bi atoms in case of Sn-Bi alloys.
Bi atoms drift in the direction of electron current, piling up at the positive end of the solder as a Bi-rich phase.
Because Bi phase is more resistive, solder joint resistance rises.

Ways to study electromigration in solder joints

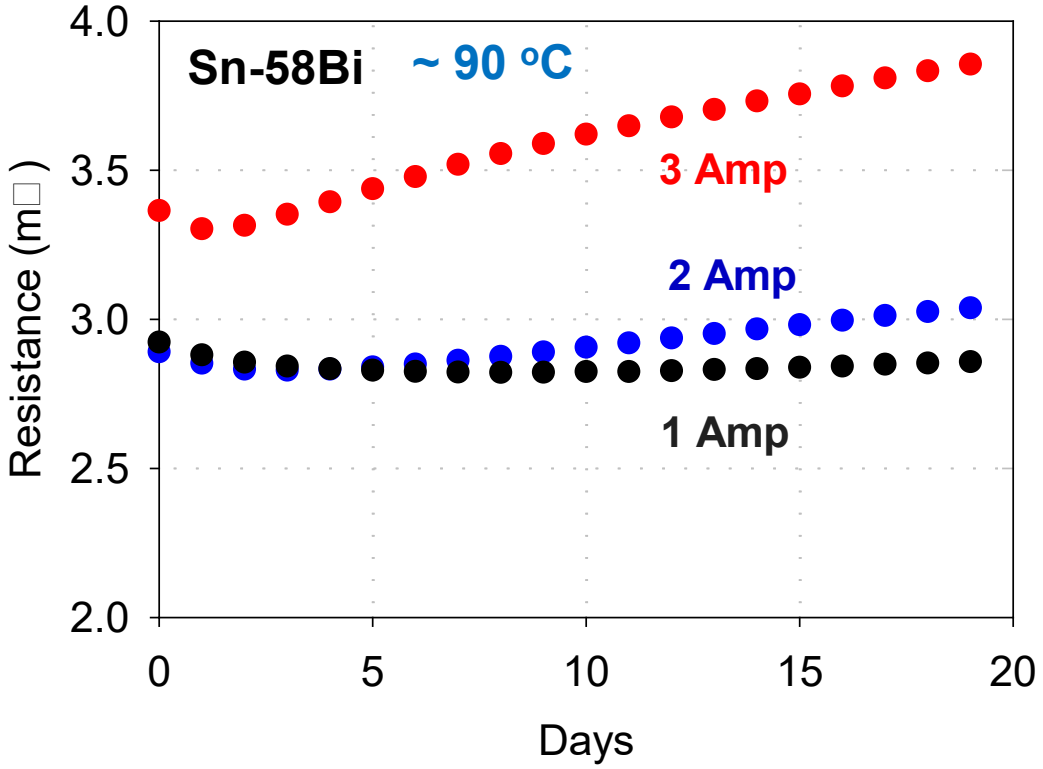
- **We can study solder joints as in actual products.**
- **Resistance is the only means to track electromigration**
- Observing Bi accumulation involves destructive analysis.



- **We can study solder joints in rectangular prism shape we will call planar solder joints.**
- Microstructural changes and Bi accumulation can be tracked non-destructively while monitoring the resistance of the solder specimens.

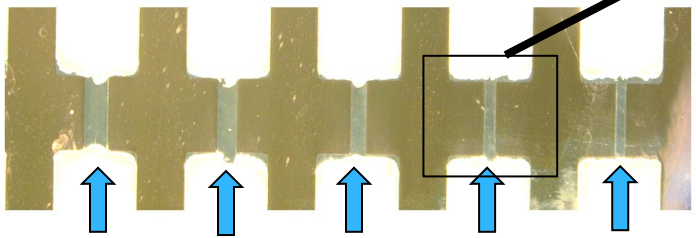


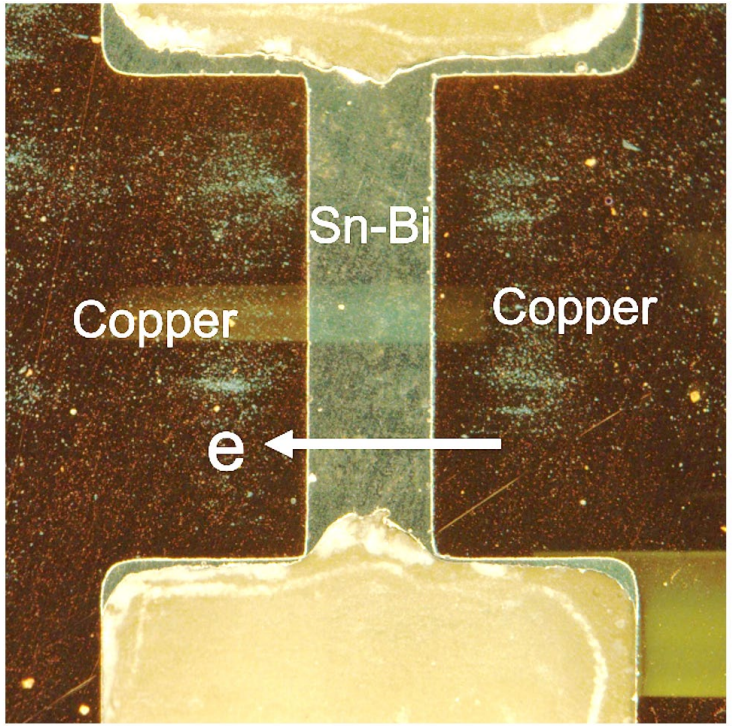
Why does the Sn-Bi solder joint resistance decrease with time at lower temperatures and current densities?



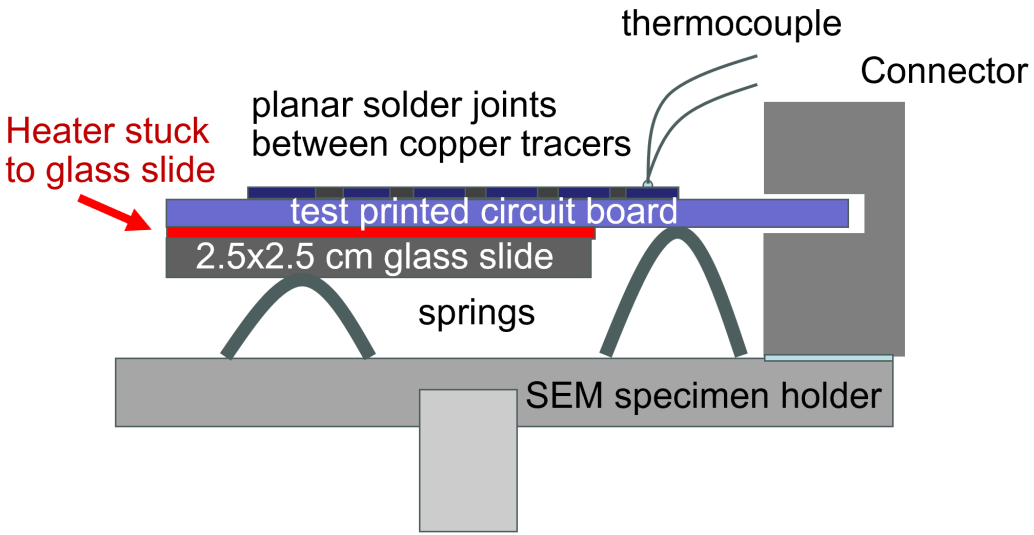
Sn-Bi planar solder joint

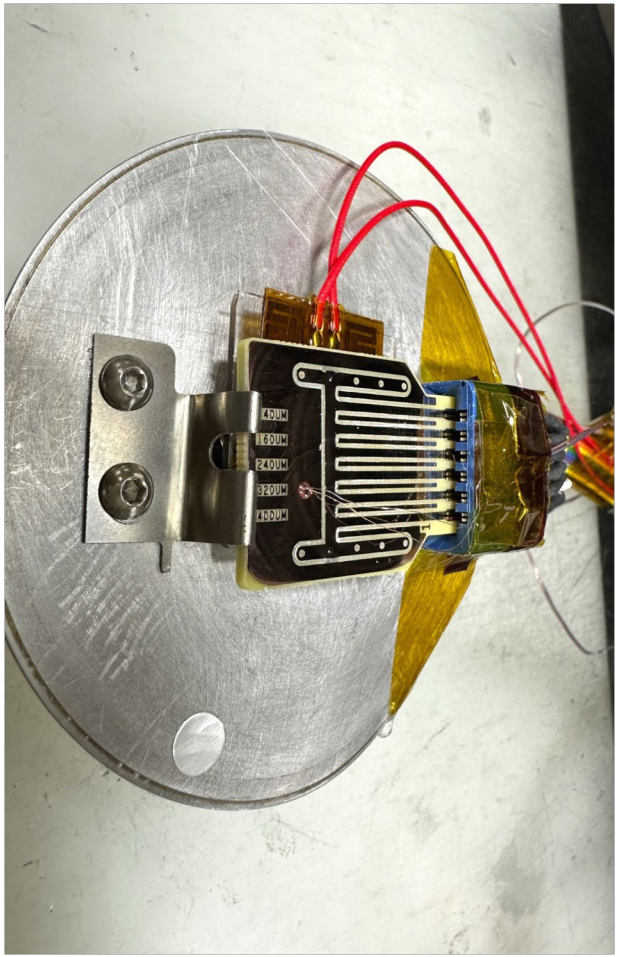
The solder planar specimens were 1.5-mm wide, 0.2 to 0.4-mm long and 30-μm thick.



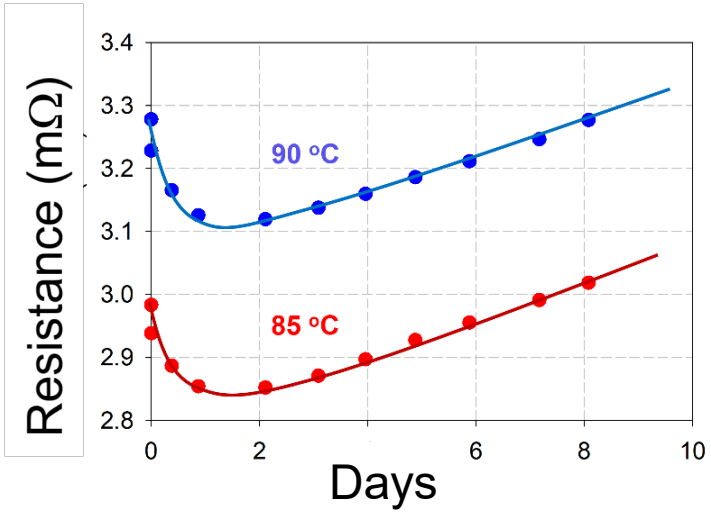


Homemade hot stage for SEM

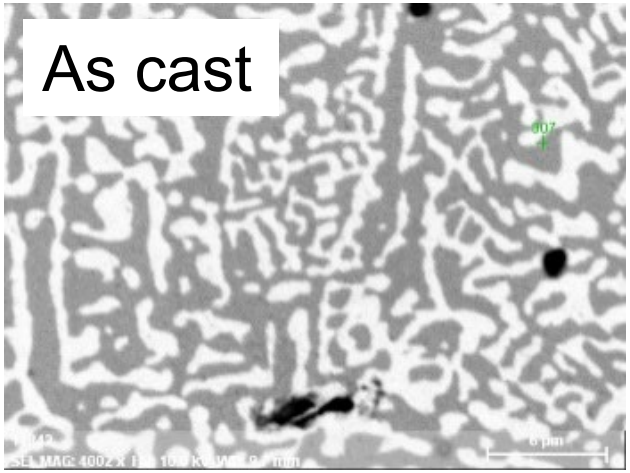


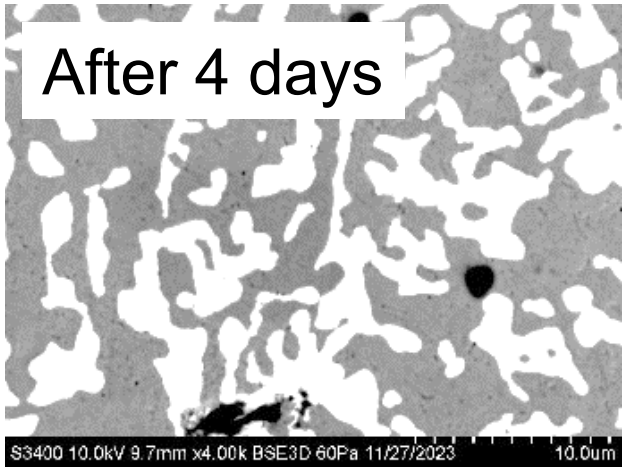


Microstructural coarsening at 4.4 A/cm^2



The Sn-rich phase matrix (darker phase) is the less resistive phase and therefore the preferred path for current flow.

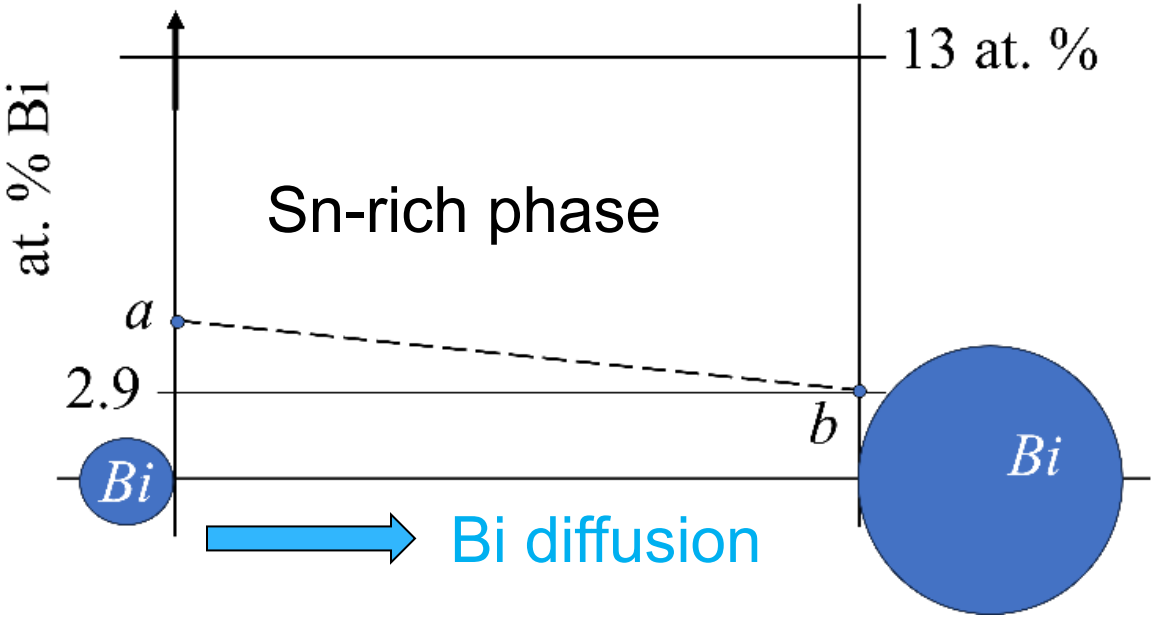




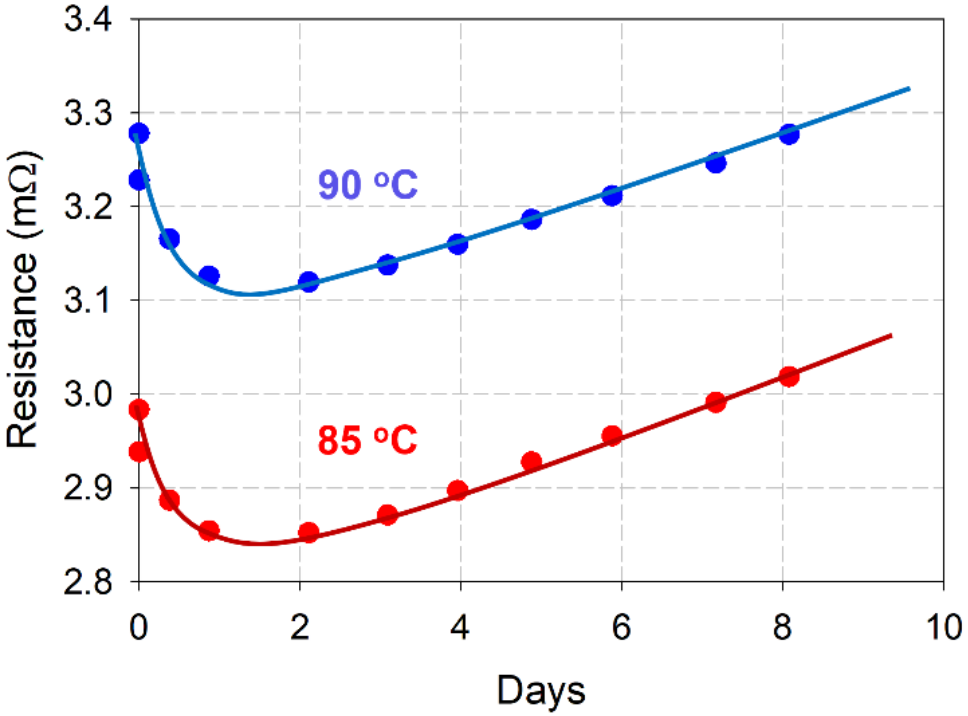
Bi particle enlargement mechanism: Ostwald ripening

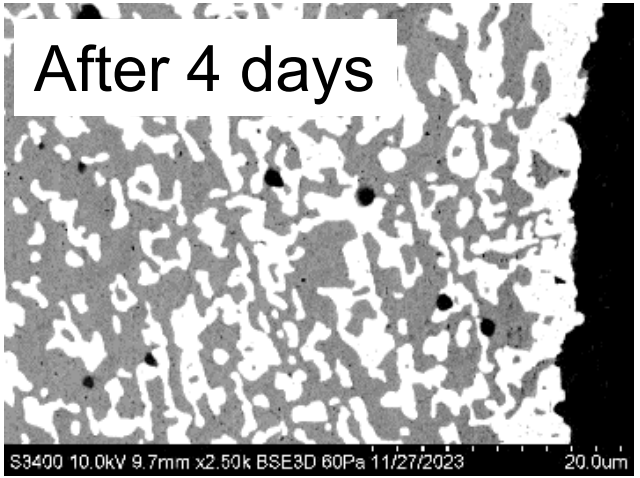
The larger the Bi particle, the lower is the Bi content of the Sn-rich phase adjacent to the Bi particle.

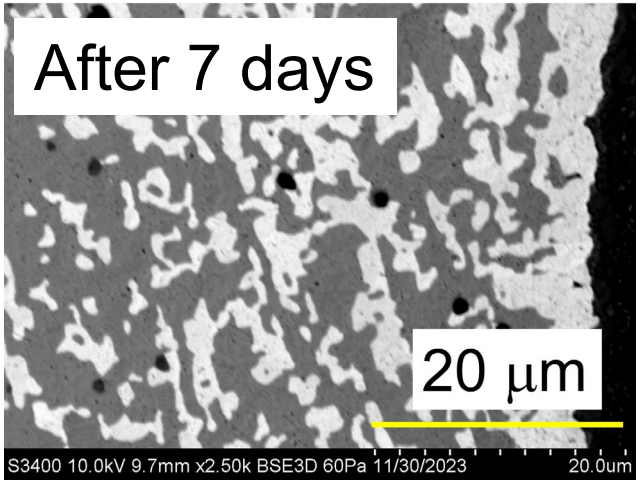
Bi atoms diffuse in the Sn-rich phase from the smaller to the larger bismuth particles.



Bismuth accumulation at anode at 4.4 A/cm^2



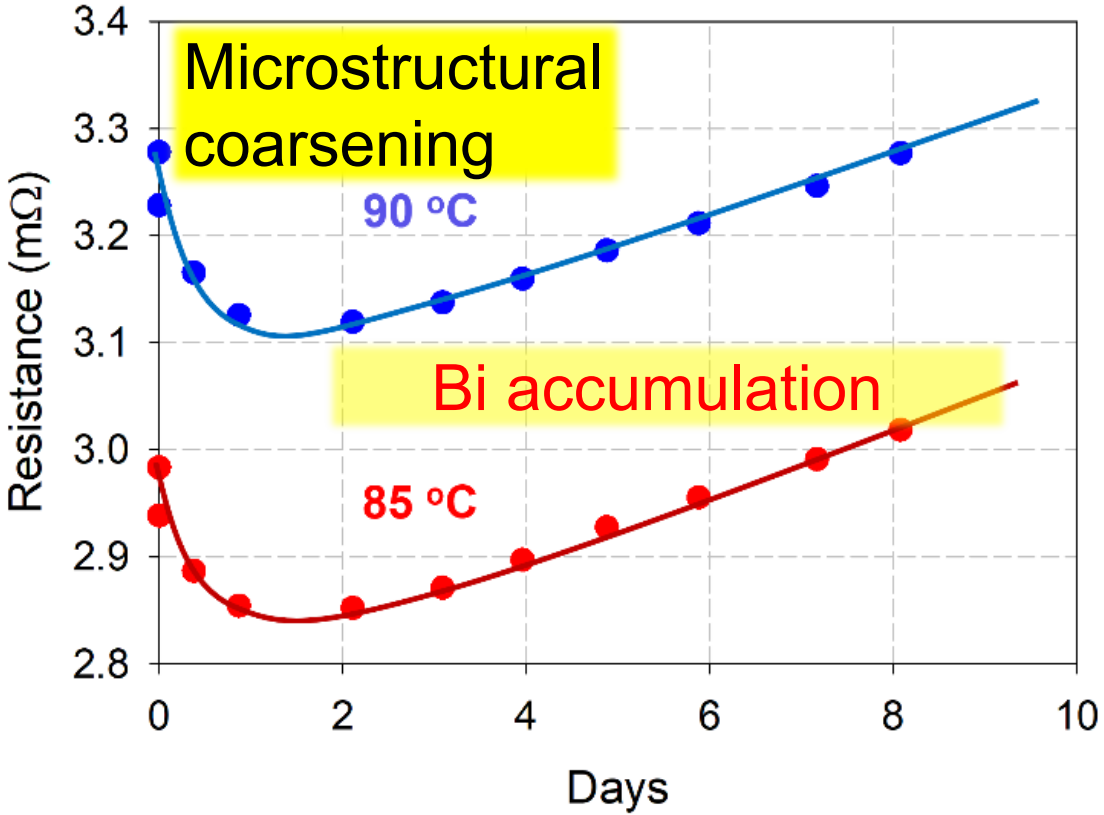




Microstructural coarsening and bismuth accumulation

Microstructural coarsening lowers joint resistance.

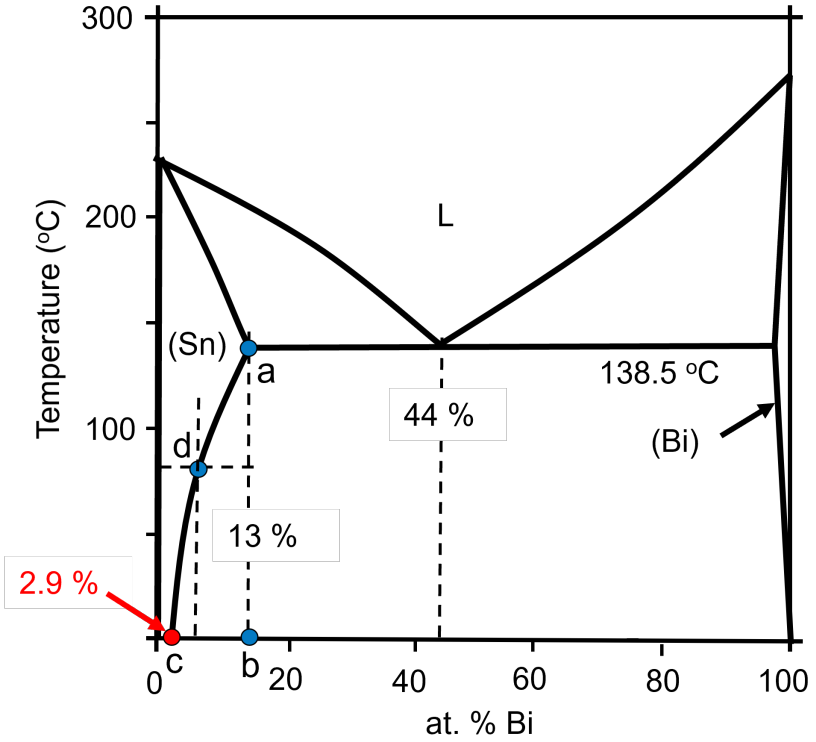
Bi accumulation raises joint resistance



Potenial second-order mechanisms

When heated to the electromigration test temperature, of say 90 °C, the Bi content of the Sn-rich phase moves from point c to d. The Sn-rich phase

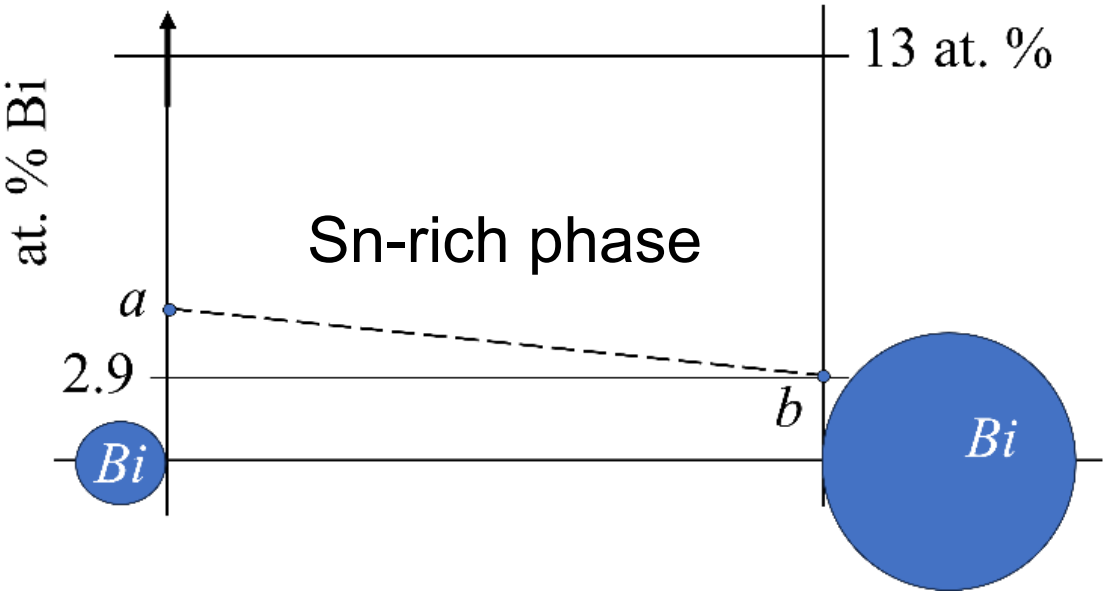
- resistivity increases ⬆
- but there is more of it. ⬇



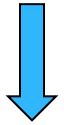
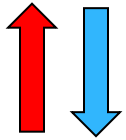
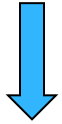
Another second-order mechanism: Because of bismuth particle enlargement, Sn-rich phase becomes less resistive

Larger bismuth particles are equilibrium with Sn-rich phase of lower Bi content.

Therefore, as Bi particles grow, the Sn-rich phase becomes less resistive.



Summary of mechanisms in the early period of electromigration at 90 °C

- **Microstructure coarsening** 
- Sn-rich phase matrix resistivity 
- Sn-rich phase matrix volume fraction increase 

Which mechanism dominates?

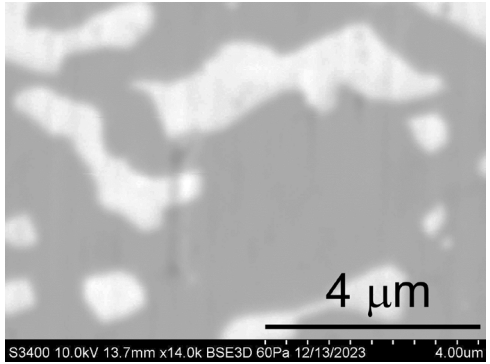
How do we separate the contribution of the mechanisms that reduce the solder alloy resistance?

- **Microstructure coarsening** ↓
- Sn-rich phase matrix resistivity decrease ↓
- Sn-rich phase matrix volume fraction increase. ↓

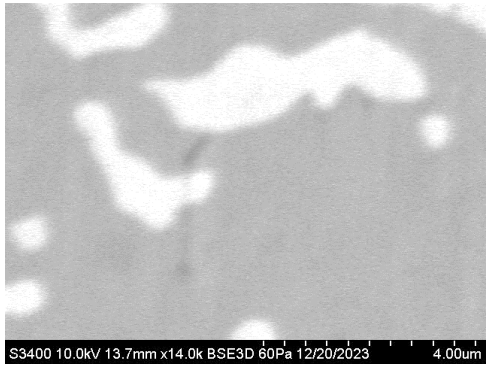
We don’t know how to.

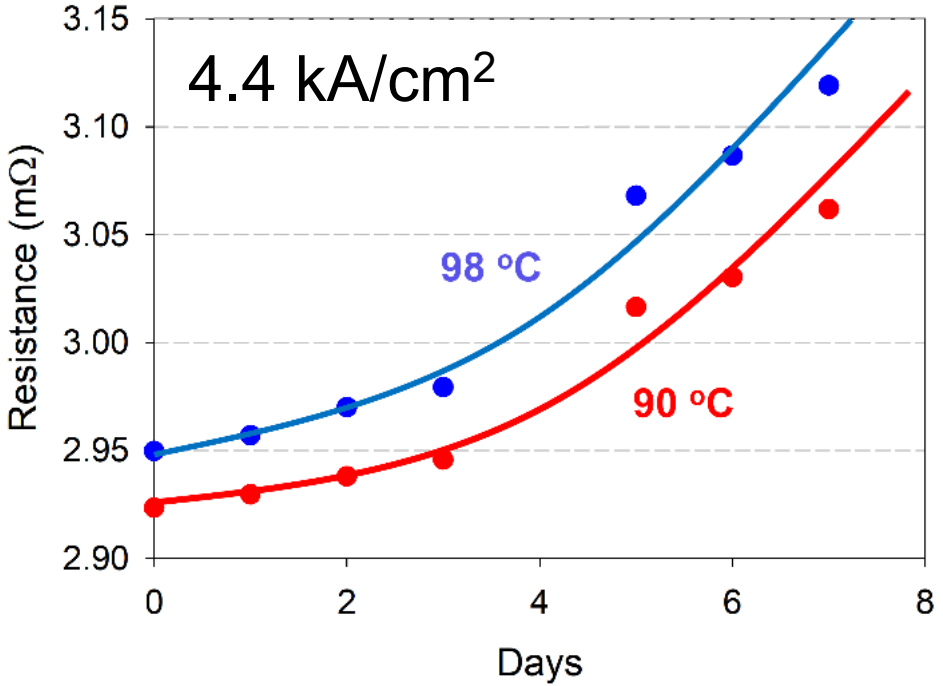
What if we started with a coarse microstructure in which the bismuth particles could not grow?

As cast



After 4 days





Conclusions

- **We think the decrease in solder joint resistance in the early period of electromigration was mainly due to microstructural coarsening, i.e., enlargement of the Bi particles.**
- Second order mechanisms may also contribute to solder joint resistance decrease:
  - Decrease in Sn-rich phase resistivity.
  - Increases the Sn-rich phase volume fraction.
- **The increase in solder joint resistance beyond the early period of electromigration was due to Bi accumulation at the anode**.

THANK YOU!

Prabjit Singh
+1-845-489-4349
pjsingh@us.ibm.com