Void formation by Kirkendall effect in solder joints

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Outline

- Introduction
- Diffusion
- Kirkendall effect
- Cases on Kirkendall void formation
- Concluding remarks

Introduction

Soldering is a complicated process

- wide variety of solder alloys, substrates, process conditions
- wetting, solidification

Large amount of data is available, for Lead Free solder additional data is required

TU Delft

Introduction

Mechanical properties of soldered joints

- Microstructure
- Inter-Metallic Compounds (IMC): nature and thickness
- Residual stresses
- Defects: ..... **Kirkendall voids** .....

Microstructure evolution determined by

- Process conditions: soldering process parameters
- Operating conditions: aging

Microstructure evolution

Soldering (T, t)

- Dissolution of substrate in liquid solder
- IMC formation
- Liquid metal penetration

Aging/Annealing (T,t)

- Diffusion
- IMC formation

Thermodynamics, kinetics

Morphology of the microstructure

Diffusion

Fick I

$$J_A = -D_A \frac{dC_A}{dx}$$

$$J_A = -D_A \frac{A\partial C_A}{\partial x} \qquad J_B = -D_B \frac{A\partial C_B}{\partial x}$$

$$D_A = \left[\frac{1}{6}\alpha^2 z\nu \exp\frac{\Delta S_m}{RT}\right]\exp\frac{-\Delta H_m}{RT} = D_{A0}\exp\frac{-Q}{RT}$$

$$v = \left(D_A - D_B\right)\frac{\partial X_A}{\partial x}$$

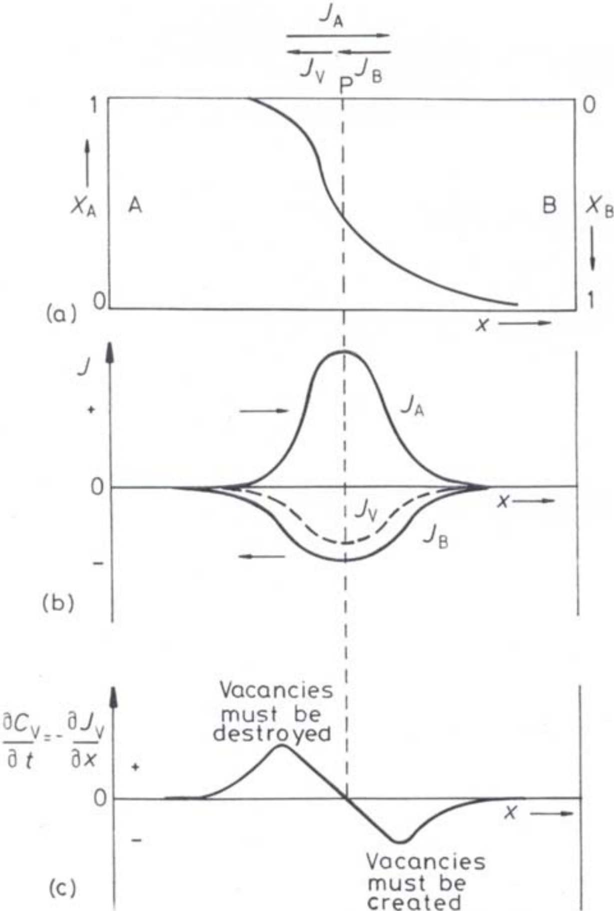
Fick II

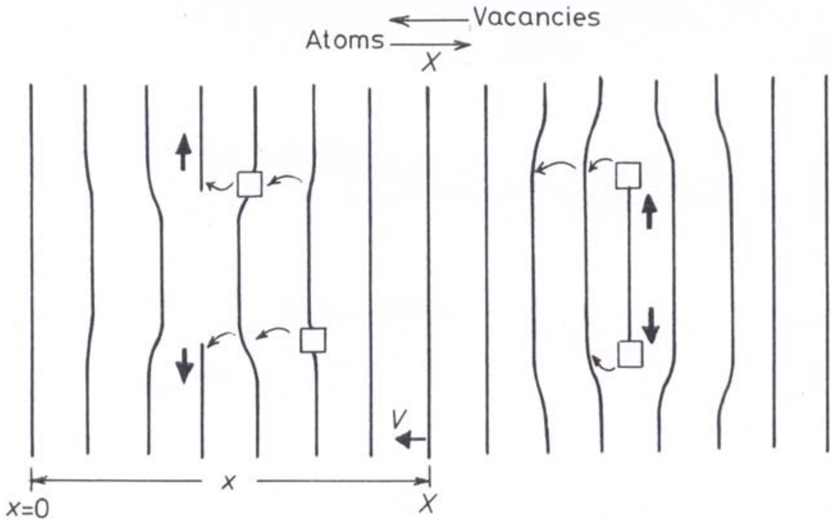
$$\frac{\partial C_A}{\partial t} = \frac{\partial}{\partial x}\left(D_A \frac{\partial C_A}{\partial x}\right)$$

$$\frac{\partial C_A}{\partial t} = \frac{\partial}{\partial x}\left(\tilde{D}\frac{\partial C_A}{\partial x}\right)$$

$$\tilde{D} = X_B D_A + X_A D_B$$

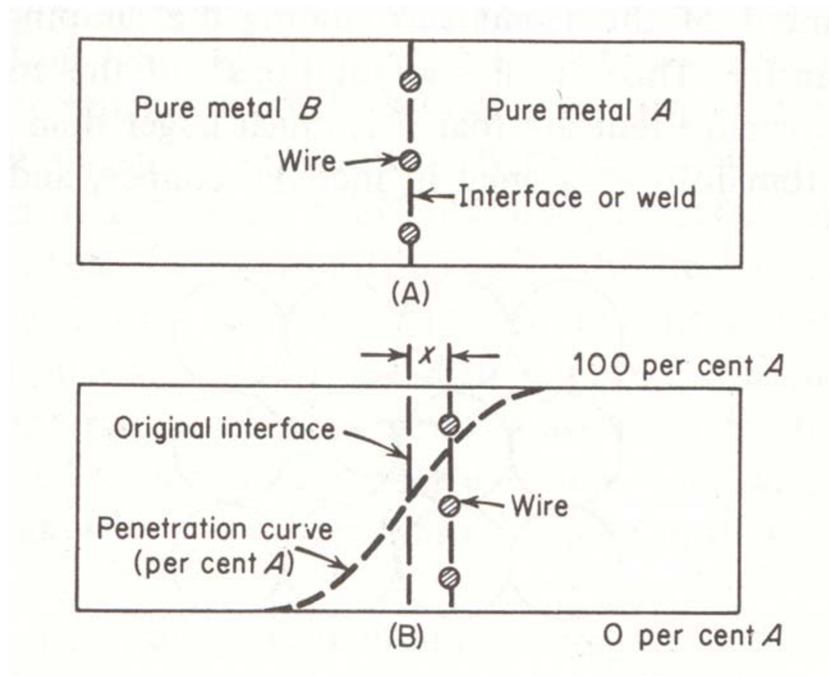
Diffusion



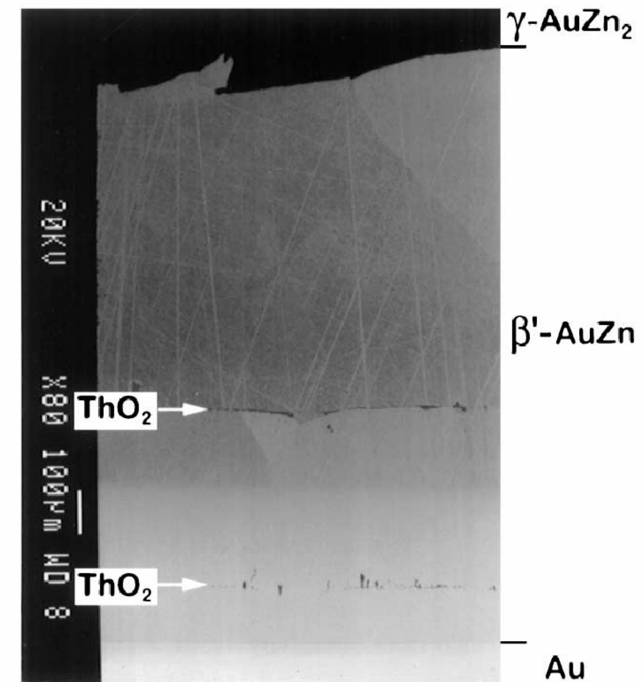


Kirkendall effect

zinc and copper



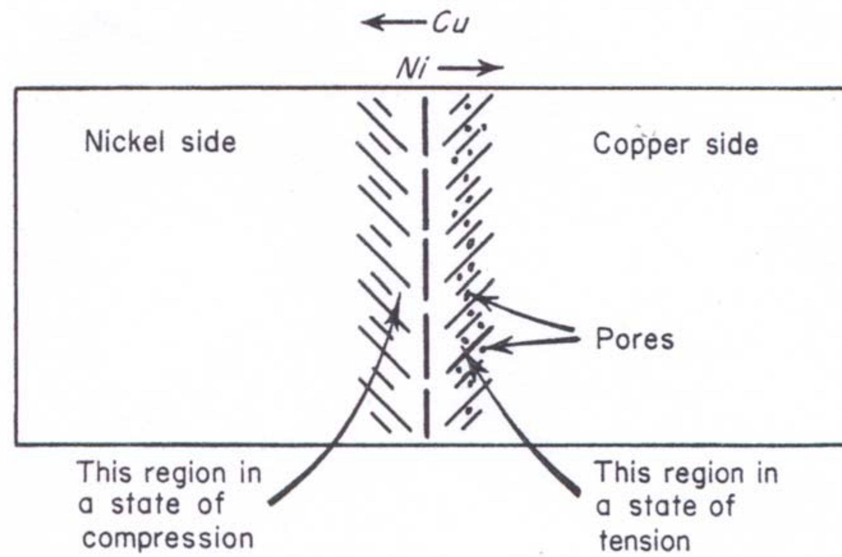
Marker movement



Multiple Kirkendall planes
stable, unstable, virtual

van Dal , Physical Review Letters, 86 (15), 2001, 3352-3355

Kirkendall voids



Case: diffusion couple Sn-Cu

- Cu_3Sn (ε)
- Cu_6Sn_5 (η)

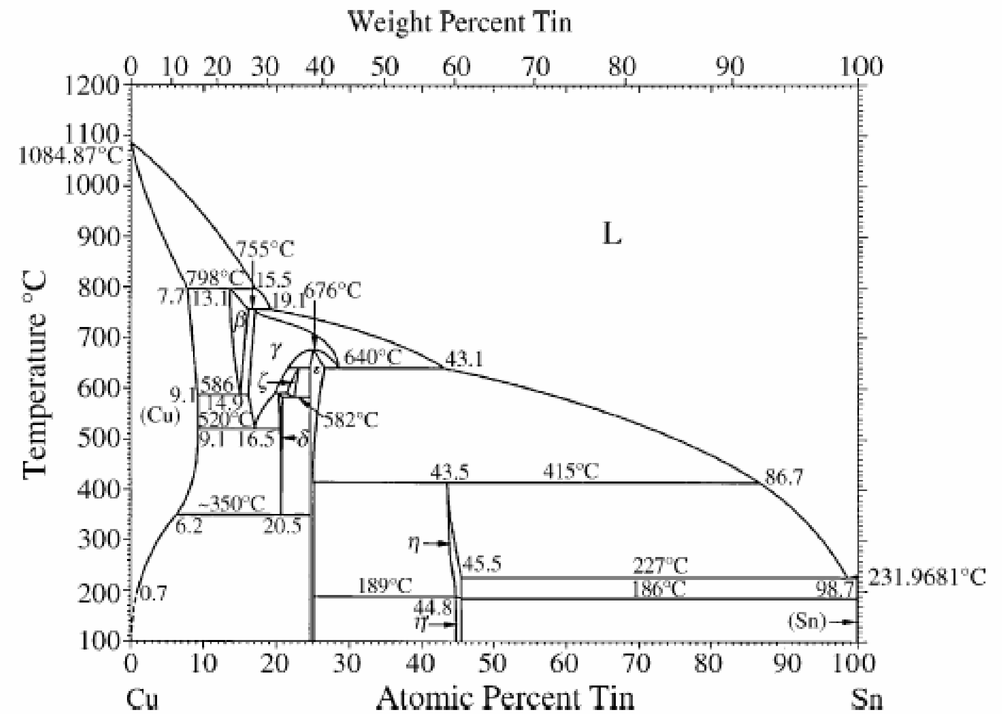


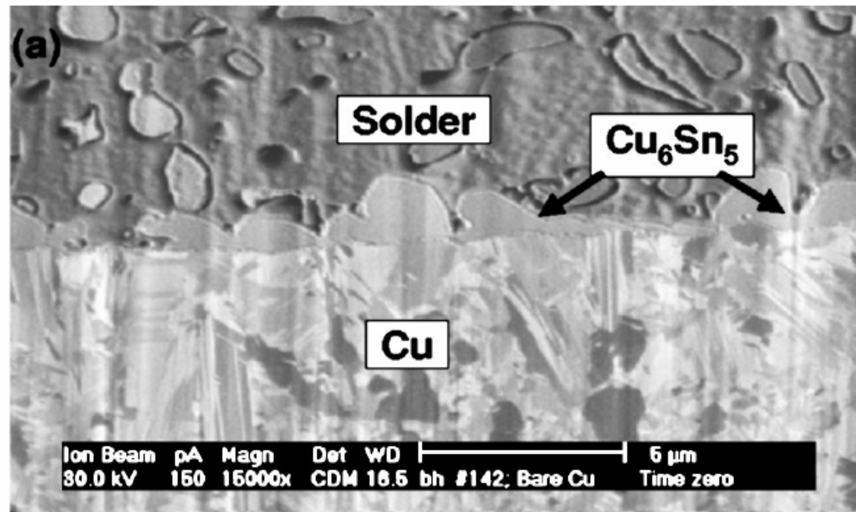
Fig. 1. Cu–Sn binary phase diagram [65].

Case: diffusion couple Sn-Cu

Soldering: solid Cu dissolves in liquid Sn (supersaturised locally)

formation of Cu_6Sn_5 (η) , scallop-like uniphase

formation of Cu_3Sn (ε), requires long contact times, thickness limited



t=0

Zeng et al. J.Appl.Phys. 97, 2005

SnPb solder - electrodeposited Cu

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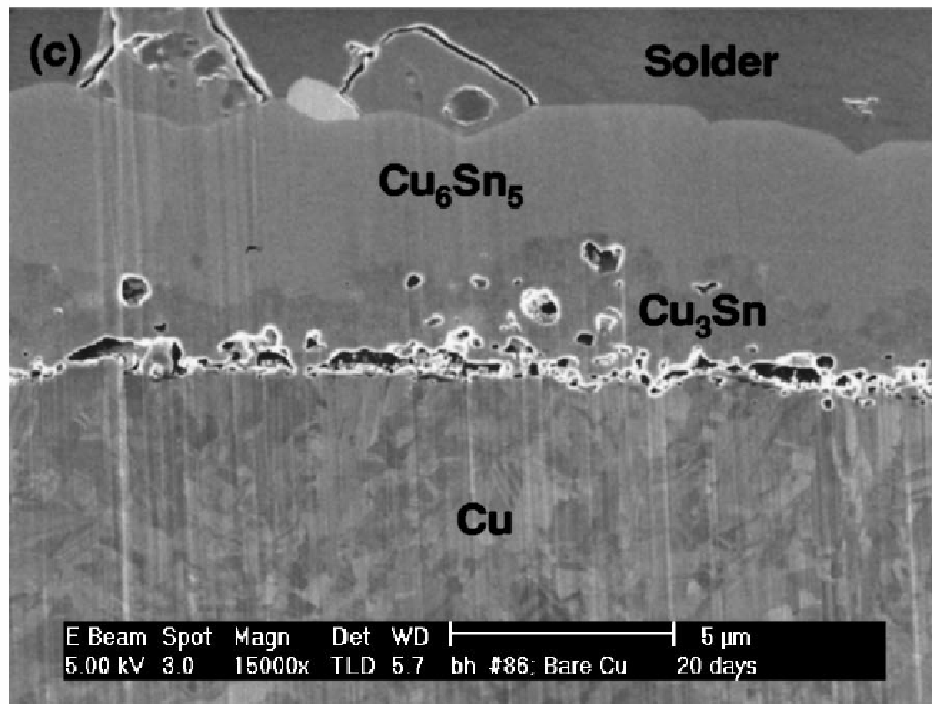
Case: diffusion couple Sn-Cu

Annealing:

Thickness of IMC increases

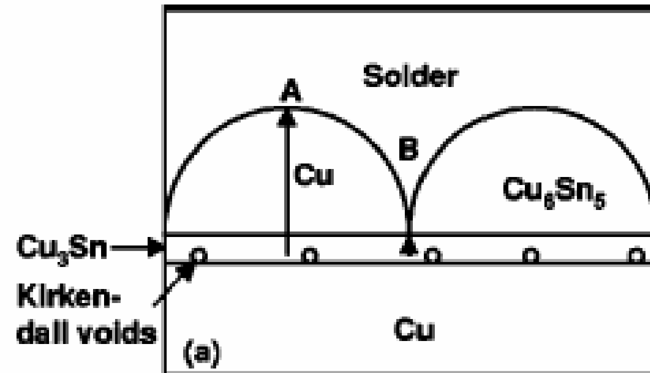
Cu_6Sn_5 (η), uniform

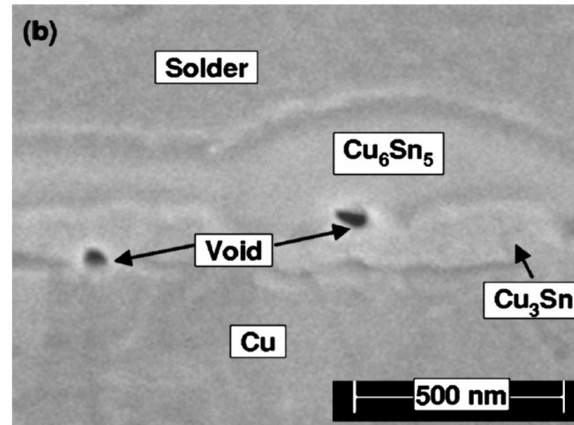
Cu_3Sn (ε), Sn diffusion exceeds Cu diffusion at higher T



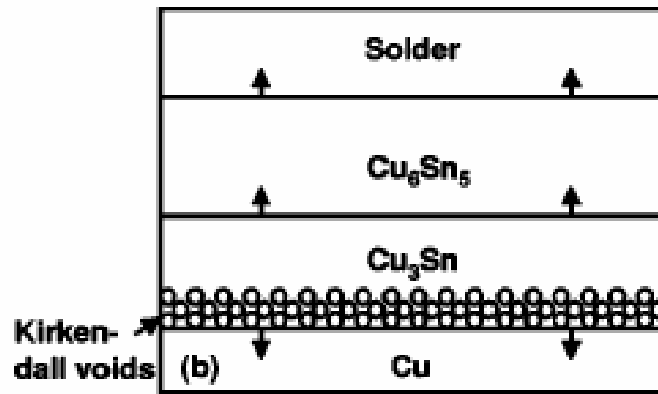
t=20days, T=150 °C

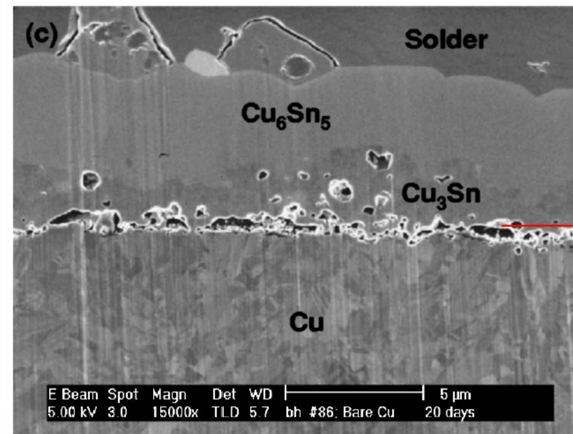
Case: diffusion couple Sn-Cu





t=0



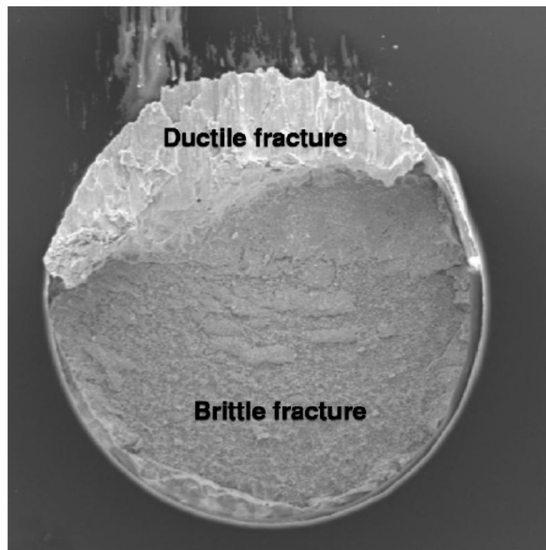


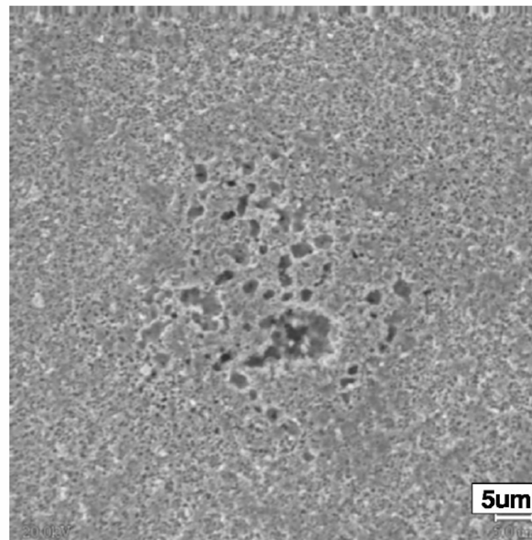
t=20days,
T=150 °C

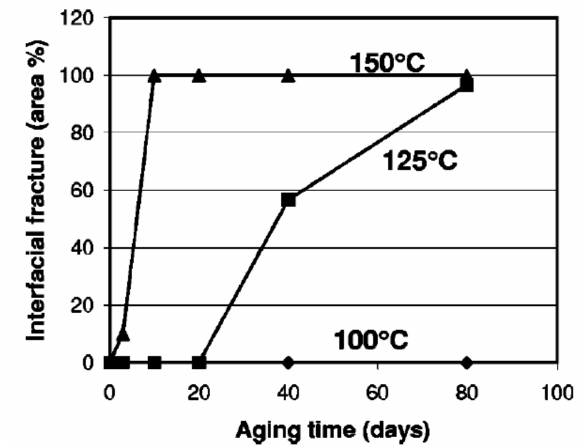
Voids influence diffusion

Case: diffusion couple Sn-Cu

- Pull and <u>shear</u> testing







Pad side

t=40days, T=125 °C

Concluding remarks

The Kirkendall effect manifests itself by the movement of marker planes in a diffusion couple system. It is the result of a net mass flow, accompanied by a vacancy flow in the opposite direction.

A large number of studies is dedicated to the microstructural evolution in solder-substrate systems. Apart from experimental work, models are becoming available to predict the microstructures.

No reference is found to predict the formation of Kirkendall voids. The voids are observed experimentally in many diffusion couple systems, but it receives not much attention.

IMC layers with Kirkendall voids are an easy path for crack propagation and determine the reliability of the solder joint.