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This Week's Citation Classic

Turnbull D. Theory of cellular precipitation. *Acta Metallurgica* 3:55-63, 1955.
[General Electric Research Laboratory, Schenectady, NY]

This paper presented an interpretation of the experimental results of H. N. Treaftis and myself[1] on the precipitation of Sn from Pb(Sn) and the generalization of this interpretation to a simple phenomenological theory of what is recognized as one of the major modes ('cellular' or 'discontinuous') of precipitation from solid solution. [The ***SCI®*** **indicates that this paper has been cited over 120 times since 1961.]**

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"I am surprised that this paper has appeared among those frequently cited. In my view, now and when it was published, it was incidental to what I thought to be a more significant experimental study by Treaftis and myself[1] of one general mode of precipitation from solid solution. At the time of these studies, at the General Electric Research Laboratory, I was active in characterizing and interpreting crystal nucleation in undercooled liquids and was especially impressed that such nucleation was almost always initiated by uncontrolled heterophase impurities, abundant in most liquid specimens, rather than by homophase fluctuations. I wondered about the importance of such fluctuations relative to nucieation on extended imperfections —dislocations and internal boundaries — in precipitation from crystalline solutions.

"About this time my attention was drawn to the careful resistometric studies of Borelius and co-workers of the rates of precipitation of tin from solid lead-tin alloys.[2] From the dependence of these rates on temperature and tin concentration, Borelius concluded that precipitation started from homophase concentration fluctuations. However, I calculated from the known diffusivity data that at the temperatures of the experiments, the times required for the necessary diffusive motions of the tin were many orders of magnitude greater than the duration of the experiments. I surmised that precipitation actually may have been effected by sweeping diffusion short circuits, such as dislocations or grain boundaries, which deposited precipitate as rods or plates behind them. Treaftis and I then repeated Borelius's experiments and, further, thoroughly characterized the isothermal time dependence of, and the effects of temperature cycling on, the precipitation rates. The latter experiments established that in any isothermal experiment all the operative nuclei were present from the beginning; no appreciable number formed by homophase fluctuations or other means in the course of precipitation. My general picture of the precipitation process deduced from the resistivity studies was then confirmed by our microscopic observations; these showed that precipitation occurred by the deposition of colonies of more or less parallel tin lamellae behind sweeping sections of grain boundaries which served as the short circuits for the transport of tin to the leading edges of the lamellae.

"I then learned that the observed mor-. phology was like that sometimes exhibited by certain other alloys and that its evolution, known as 'discontinuous' precipitation, had been interpreted qualitatively, but quite correctly, by Cyril Smith.[3] The paper listed above presented my interpretation of our experiments and the generalization of it to a phenomenological theory of 'cellular' (or 'discontinuous') precipitation. A central feature of my highly simplified theory was the adaptation of Zener's theory[4] for the volume diffusion controlled growth of pearlite colonies in steel to the case of boundary controlled growth. Later, John Cahn[5] developed a more rigorous theory for the process which had my theory as a limiting case.

"I suppose that my paper may have been widely cited because it drew attention to what has come to be recognized as one of the major modes of precipitation from solids and because of its analytical simplicity. More recent experimental developments have been reviewed by myself and K.N. Tu."[6]

1. **Turnbull D & Treaftis H** N. Kinetics of precipitation of tin from lead-tin solid solutions. *Acta Metallurgica* 3:43-54, 1955. [The SCI indicates that this paper has been cited over 50 times since 1961.]
2. **Borelius G, Larris F & Ohisson** E. Kinetics of precipitation in Pb-Sn alloys. *Ark. Maternal. Astron. Fys.* 31A:1-19. 1944.
3. **Smith** C S. Microstructure. *Trans. Amer. Soc. Metals* 45:533-75, 1953.
4. **Zener** C. Kinetics of the decomposition of austenite. *Trans. AIME* 167:550-95, 1946.
5. **Cahn J W.** The kinetics of cellular segregation reactions. *Acta Metallurgica* 7:18-28, 1959.
6. **Turnbull D** & **Tu K** N. Cellular and proteolytic reactions. *Phase transformations.* Metals Park, OH: American Society for Metals. 1970. p. 487-95.