PURDUE
UNIVERSITY
School of Materials Engineering

Lead-Free Electronics Affecting Implantable Devices

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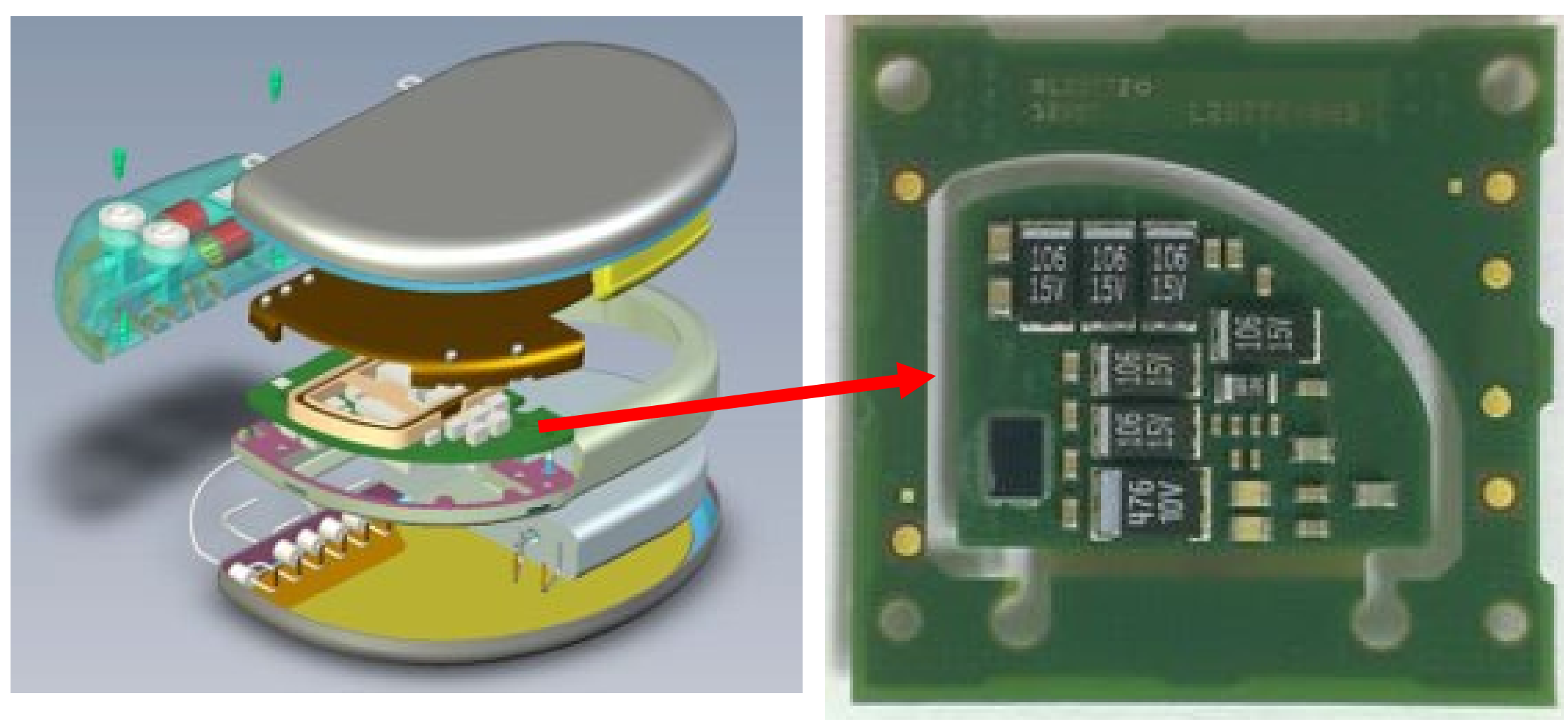
Industrial Sponsors: Dr. Peter Tortorici from Medtronic

The objective of this project was to formulate an accelerated aging method that would create samples with similar characteristics to Medtronic provided Sn-Pb, SAC305, and SAC105 solder samples aged at room temperature and body temperature for ~9 years. An aging experiment was performed on SAC305, SAC105, and Sn-Pb solder at 85°C and 125°C, for 14 weeks and 3 weeks, respectively. Samples aged at 125°C for 2 weeks and 85°C for 7 weeks were identified as the most similar in morphology and chemical composition to the Medtronic ~9 year aged samples.

This work is sponsored by Medtronic, Minneapolis, MN

Project Background

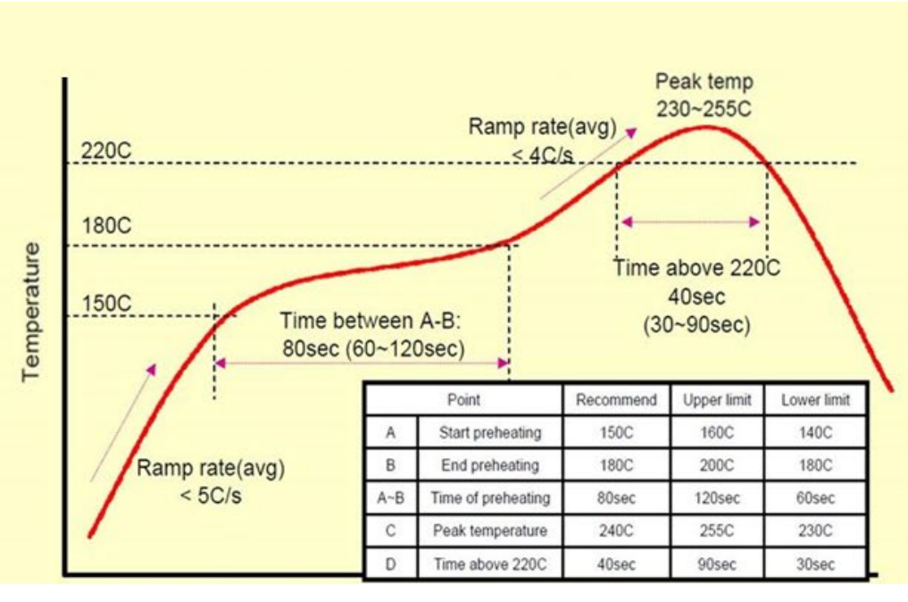
Medtronic currently employs Sn-Pb solder for electronics assemblies which are used in implantable therapies for cardiac and neurological diseases. The current solder alloy has a long history of high reliability in these applications. The introduction of worldwide legislation has resulted in the gradual conversion from Sn-Pb to Pb-free solders in electronics manufacturing. Some industries, such as aerospace, and active implantables are still exempted from compliance, however, they only comprise about 1% of domestic electronics manufacturing. If Medtronic were to entertain a transition to Pb-free solder alloys in these applications, then a thorough understanding of the performance and aging of these alloys in applications are needed, as device lifetimes can exceed 10 years in patients. The development of accelerating aging conditions to map to device lifetime in patients is required in order to determine reliability of these materials in these applications. This project team focused on determining an accelerating aging condition of Pb-free solders that would correlate to samples being aged at 37°C, which have passed the ~9 year aging point.



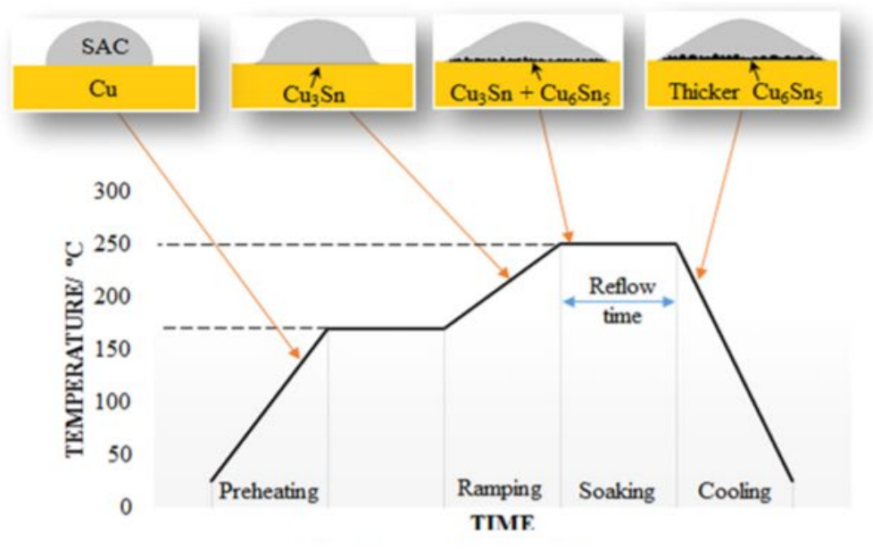
Tortorici, P. (2021). *Medtronic Basic Information* [PowerPoint slides]. Medtronic PLC, Tempe, AZ.

Experimental Procedure

- **Reflow and Aging:** Two types of samples were analyzed during this project. Medtronic provided Sn-Pb solder control samples removed from the assembly line and aged at room temperature for ~9 years, SAC305 solder samples aged at 37°C for ~9 years, and SAC105 solder samples aged at 37°C for ~9 years. These samples were reflowed in an industrial setting. The approximate SAC solder reflow profile is shown in the left image below.

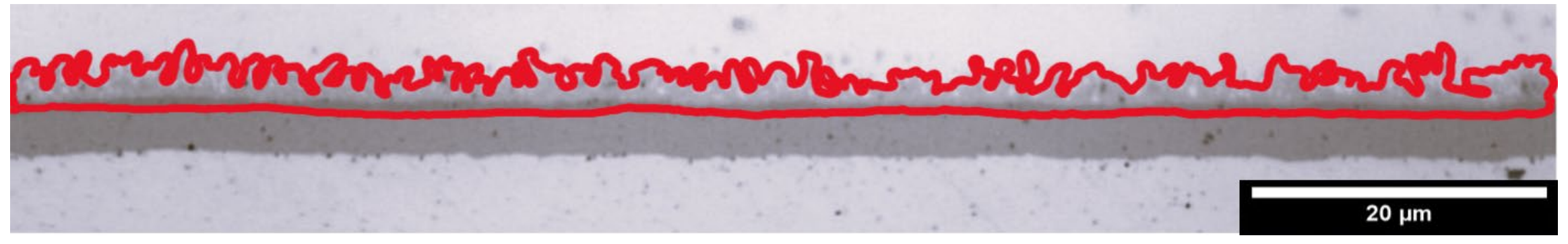


	Point	Recommend	Upper limit	Lower limit
A	Start preheating	150C	160C	140C
B	End preheating	180C	200C	180C
A~B	Time of preheating	80sec	120sec	60sec
C	Peak temperature	240C	255C	230C
D	Time above 220C	40sec	90sec	30sec



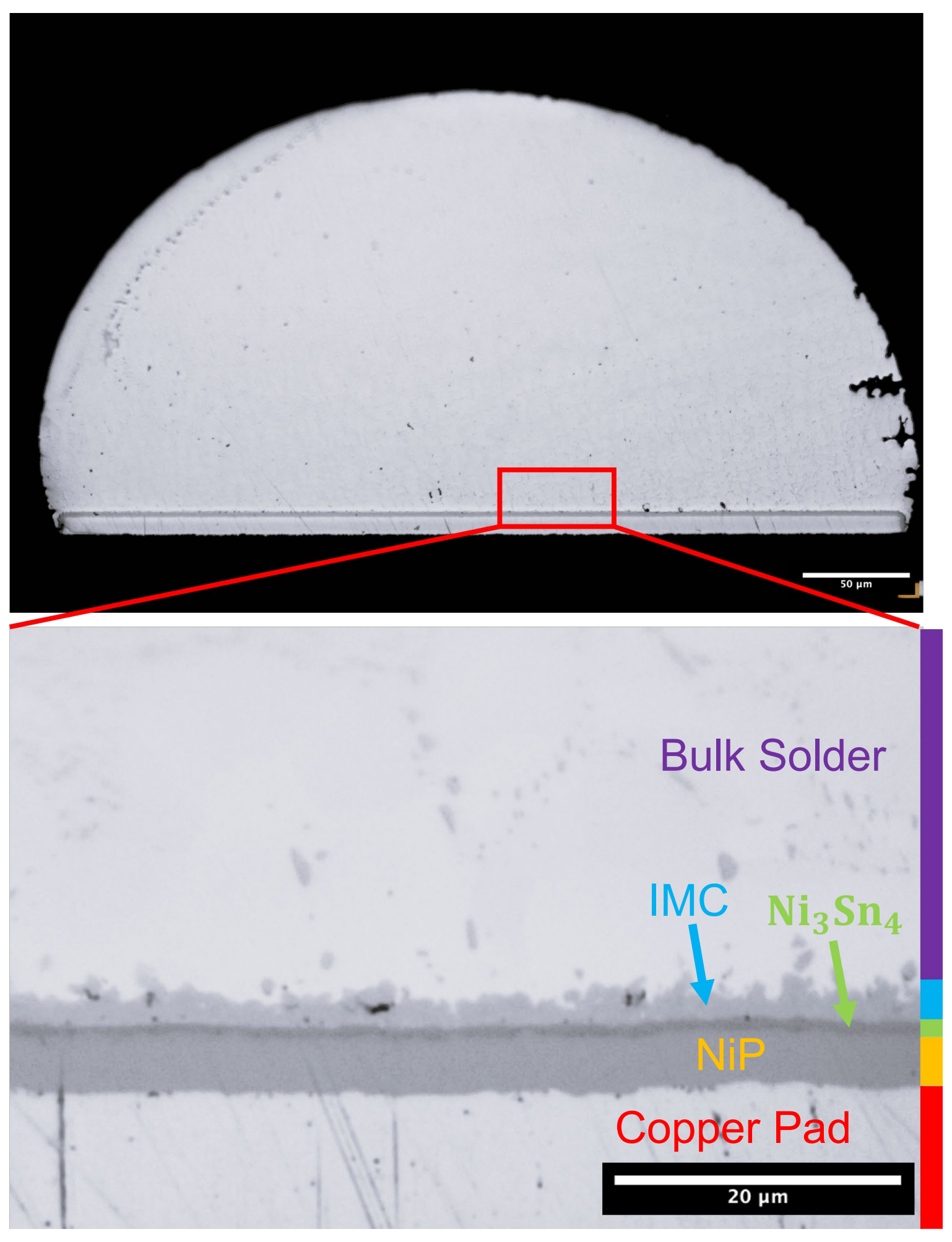
The second type of sample examined in this project were Sn-Pb, SAC305, and SAC105 solders which were reflowed on ENEPIG circuit boards provided by Medtronic in a DDM Novastar tabletop reflow oven. The approximate SAC solder reflow profile is shown above in the right image. Following reflow, samples were placed in 85°C and 125°C furnaces for 14 and 3 weeks respectively while samples were removed at set intervals. The aging experiment was modeled after the correlation that every increase of 10°C in aging temperature halves the time needed. A representative image of these samples after reflow is show

- **Sectioning, Mounting, and Polishing** Samples were sectioned via diamond saw, mounted in epoxy resin, and polished.
- **Optical Microscopy** was performed for initial characterization.
- **Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDS)** were performed on the Quanta 3D Machine using Low Vacuum Mode and the appropriate voltage and intensity for each sample. ImageJ was used to image process.
- **IMC Thickness Measurements** were taken from optical and SEM images by measuring the area of the IMC layer (shown by the red outline in the image below) which was divided by the length of the image to determine the average IMC thickness.



- **Nanoindentation** was performed on a Hysitron Triboindenter with a Berkovich tip and using force while loading up to 200 µN to measure hardness and calculate modulus upon unload.

Key Results - Microstructure

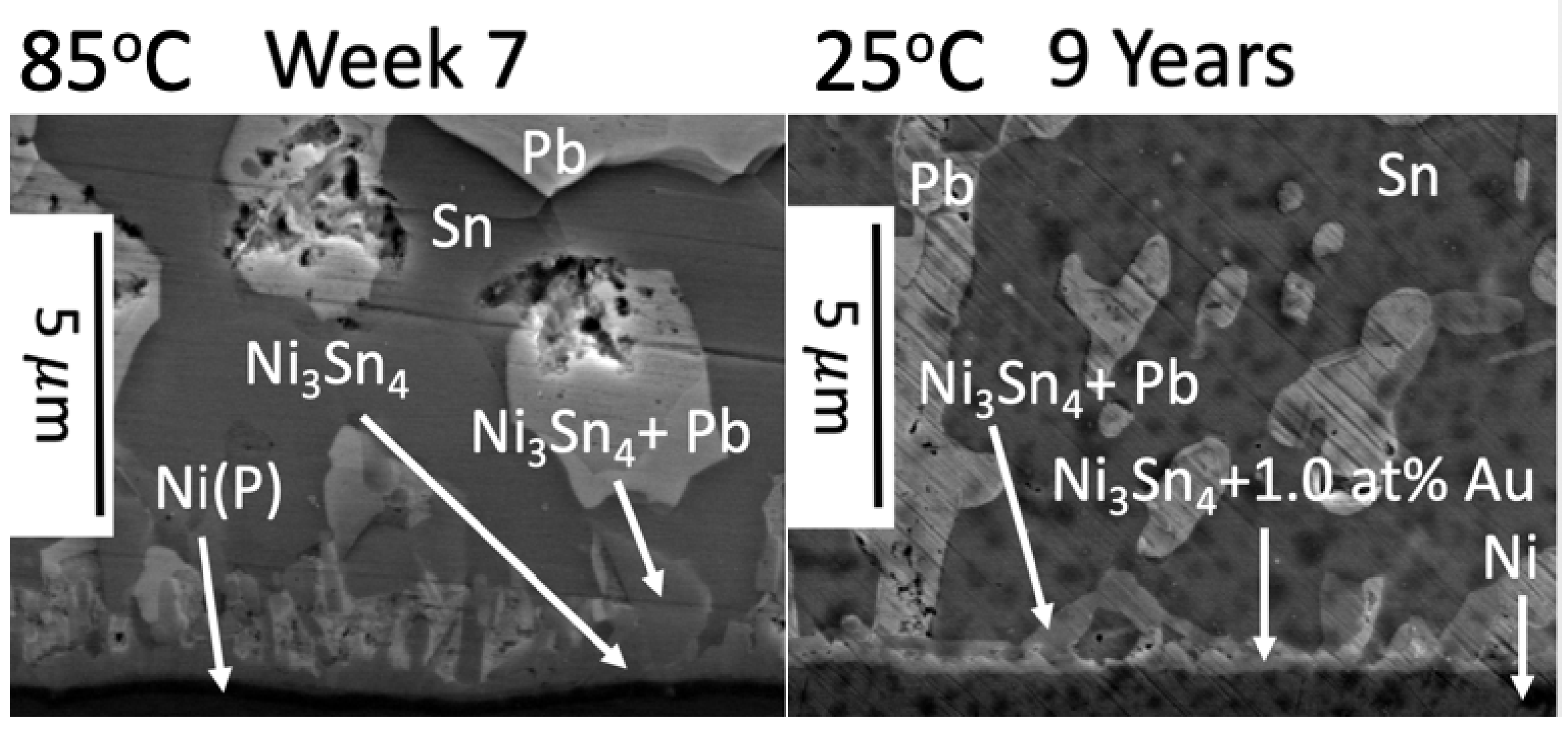


The IMC layer of interest is the Cu_6Sn_5 layer present at the interface of the surface finish and bulk solder. By examining the microstructure of the interface, the growth can be determined based on how much the Cu_6Sn_5 layer increases for each aging increment. This was accomplished using optical images to image a large area then measuring the IMC thickness across the image.

IMC identification and layer thickness comparison of the Medtronic aged samples and the aging study samples can be seen below in the SEM images. The samples aged at 85°C for 7 weeks in the aging study are shown as they are representative of the aging study experiments, and they are also the samples that exhibited IMC composition and thickness similar to the Medtronic aged samples.

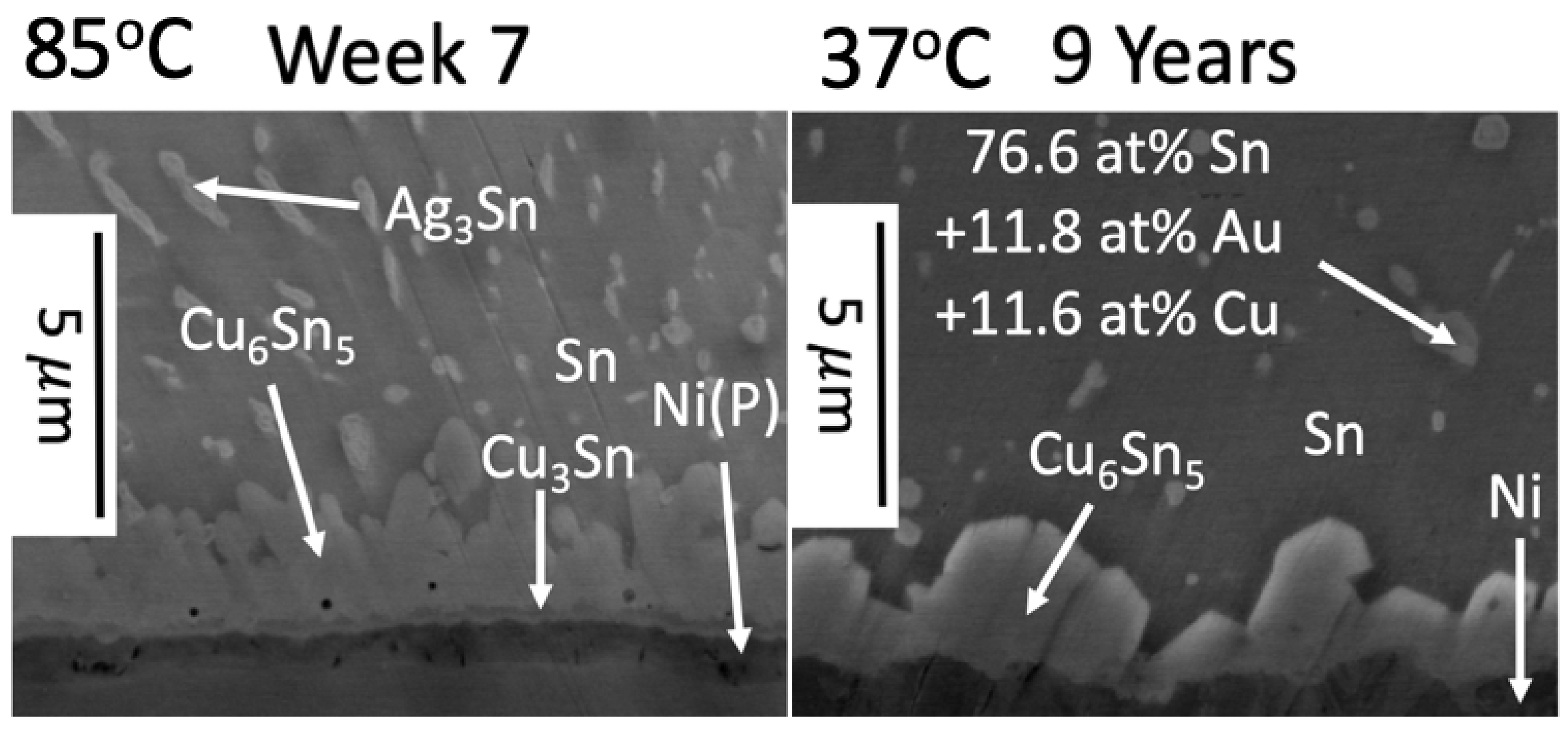
Both the Sn-Pb Medtronic and aging study samples exhibited two different IMC layers; a Ni_3Sn_4 layer and a Ni_3Sn_4 layer with some Pb in it, and both had typical eutectic phases in the solder bulk; Sn matrix with Pb phases. However, only the Medtronic samples had traces of Au.

Sn-Pb



Both the SAC305 Medtronic and aging study samples exhibited the Cu_3Sn IMC layer. However, the aging study samples had an additional IMC layer above the Ni layer, identified as Cu_6Sn_5 and the Medtronic samples had traces of Au. In the solder bulk, the aging study samples had Ag_3Sn particles, and it is also believed that the particles in the bulk of the Medtronic samples are Ag_3Sn particles. The thickness of the Cu_6Sn_5 IMC is approximately the same for both the aging study samples and the Medtronic samples.

SAC305



Acknowledgements

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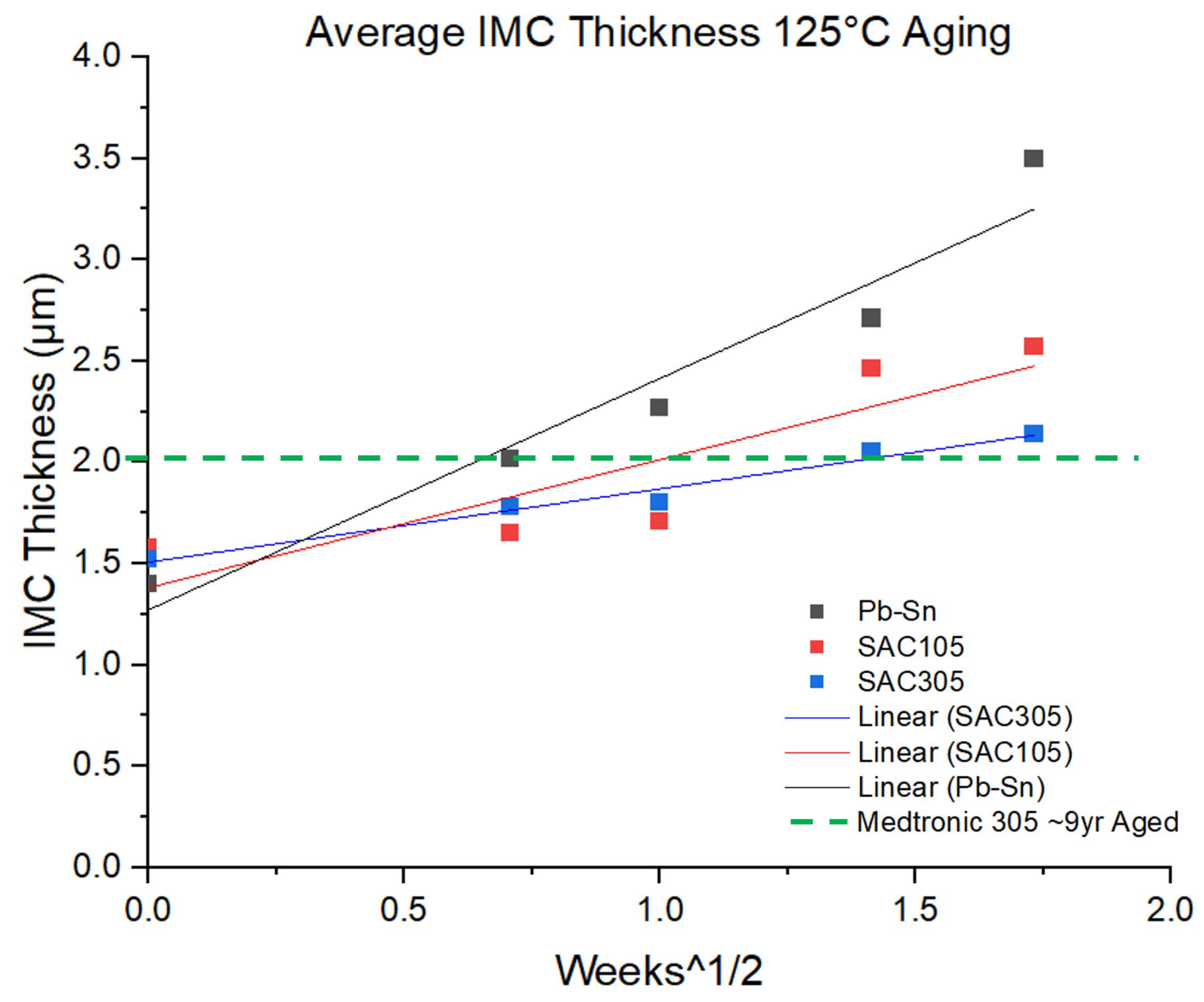
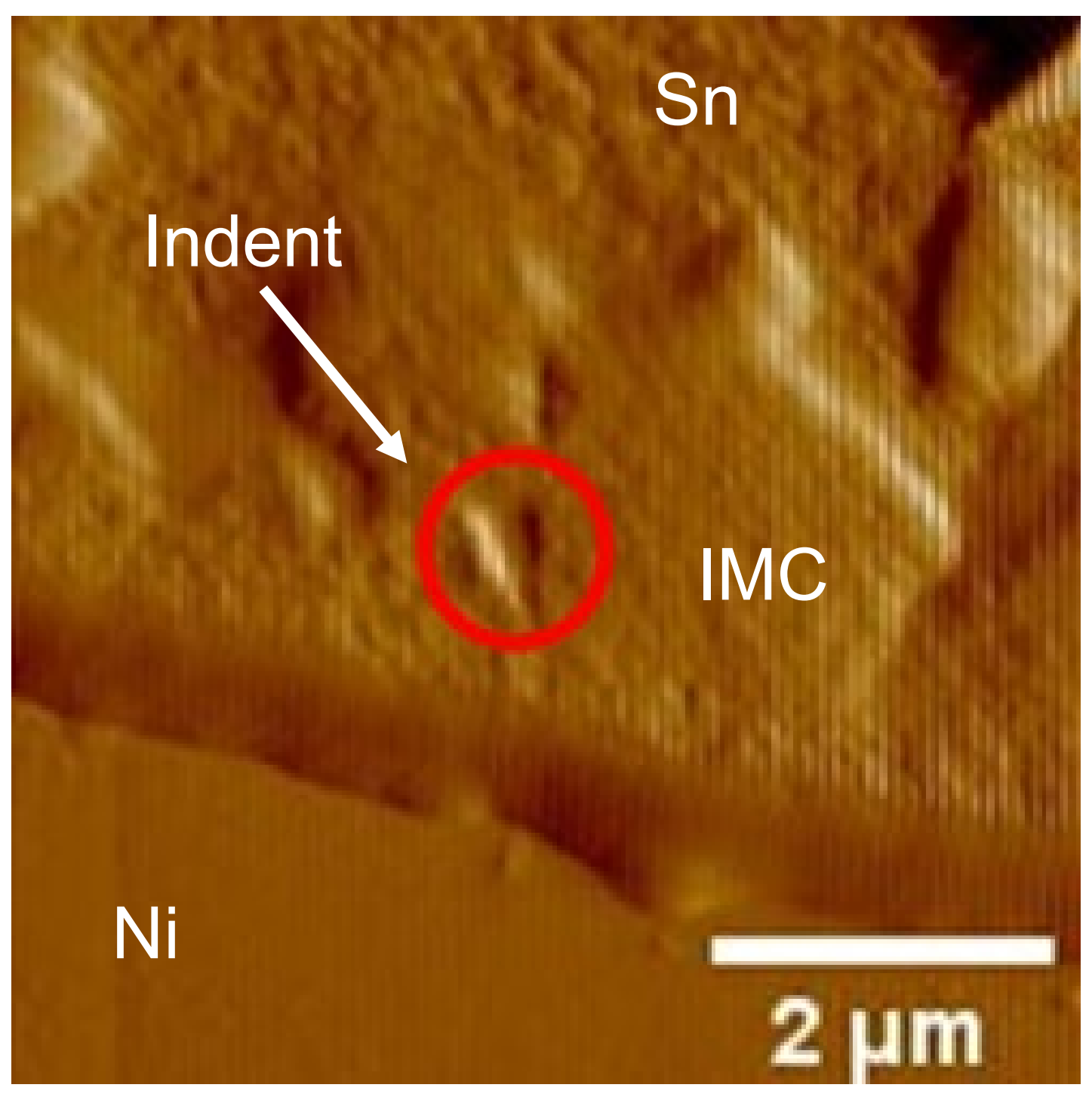
Key Results - Properties

The figure comparing IMC thickness versus time shows a linear relationship between time to the ½ and thickness. This is to be expected and is indicative of bulk diffusion being the controlling mechanism.



The data also shows that there were different growth rates for each type of solder at 125°C. Looking at the growth rates it is evident that the Sn-Pb solder grew at the fastest rate while the SAC solders grew at a slower rate, with the SAC305 having a higher initial intermetallic thickness and SAC105 growing slightly faster than SAC305. Additionally, a line is shown on the plot where the aged Medtronic samples measured for SAC305. This shows that the SAC305 at week 2 had a similar intermetallic layer thickness as the Medtronic samples. This prediction was based on a back of the envelope calculation in which for every 10°C you halve the time needed to age to obtain an intermetallic of the same thickness. Using this window, we were able to estimate how long to age our solders. This allows for a window to be created with 2 weeks at 125°C as one of the bounds, then 7 weeks at 85°C as the other bound. This means that for any future aging, samples can be aged from 85°C to 125°C from a time of 7 to 2 weeks based on temperature and the thickness of the Cu_6Sn_5 layer. This will result in a similar sample to the ~9 year sample aged at 37°C. This allows for accelerated aging of SAC305 solder.



Nanoindentation can be used to test mechanical properties of small samples. The mechanical properties are important because if fracture occurs the electrical connections to the components will be broken. There is no significant difference between the modulus of the IMC or the Sn-matrix of the SAC105 and SAC305 samples as shown by t-testing. This is expected as modulus is a material property. The moduli were also similar to values found in literature. This data can be used as a reliable base line for aged samples in the future. There was a significant difference between the hardness of the SAC105 and SAC305 samples. This could affect the fracture strength of the solder joints and harder materials could be more likely to fracture. Therefore, there is concern over the growth of the intermetallic layers. The increased hardness of this layer over the Sn-matrix causes more fractures to occur in this area. Below are the values of moduli and hardness's of the different layers for the different solder types.

	IMC H (GPa)	IMC E (GPa)	Sn-Matrix H (GPa)	Sn-Matrix E (GPa)
SAC105	1.79 ± 0.59	65.56 ± 12.65	0.35 ± 0.11	49.39 ± 13.85
SAC305	0.69 ± 0.17	59.61 ± 12.01	0.19 ± 0.8	44.80 ± 5.86

Conclusions & Recommendations

Samples aged at 125°C for 2 weeks and 85°C for 7 weeks were identified as most similar in IMC and solder morphology and IMC chemical compositions to the Medtronic provided room temperature and body temperature ~9 year aged samples.

Additional verification/validation for this project could occur by:
- studying further aging temperatures
- further mechanical and electrical reliability testing
- performing more extensive nanoindentation
- performing EBSD crystallographic texture studies

MSE 430 - 440: Materials Processing and Design