SWTEST
2021 CONFERENCE
PROBE TODAY,
FOR TOMORROW

30 TH ANNIVERSARY

EVALUATING THE HIGH TEMPERATURE CREEP PERFORMANCE OF MEMS VERTICAL TECHNOLOGY PROBES

Rambod Tabasi
Raul Molina
Dominik Schmidt

TRANSLARITY®

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Agenda

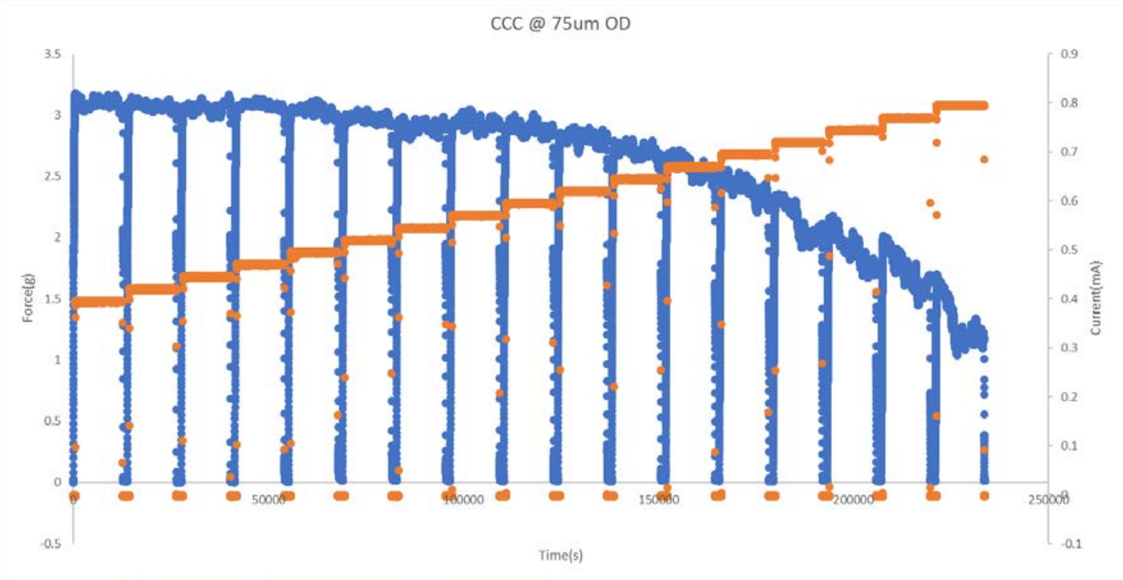
- Introduction / Background
- Methods / Materials / Procedures
- Results / Relevant Findings / Key Data
- Discussion of Results
- Impact of Improved Materials
- Follow-On Work

Introduction

- **Wafer testing is moving towards higher temperatures**
  - 125C becoming the norm, 150C is common, 185C for some applications
- **While probecards have been built to handle these, there are many related long-term metallurgical issues**
  - Here we explore creep as a reliability problem
  - We present the issue in terms of probecard lifetime and explore solutions with several improved metal alloys

CCC Definition

- **“20% force drop; ISMI standard”**
- **Force drop can be due to multiple factors including EvsT, σ_Y vs T and/ or creep**
- **Does ISMI CCC tell us everything about probe life at temperature?**



Creep - Overview

What is creep?

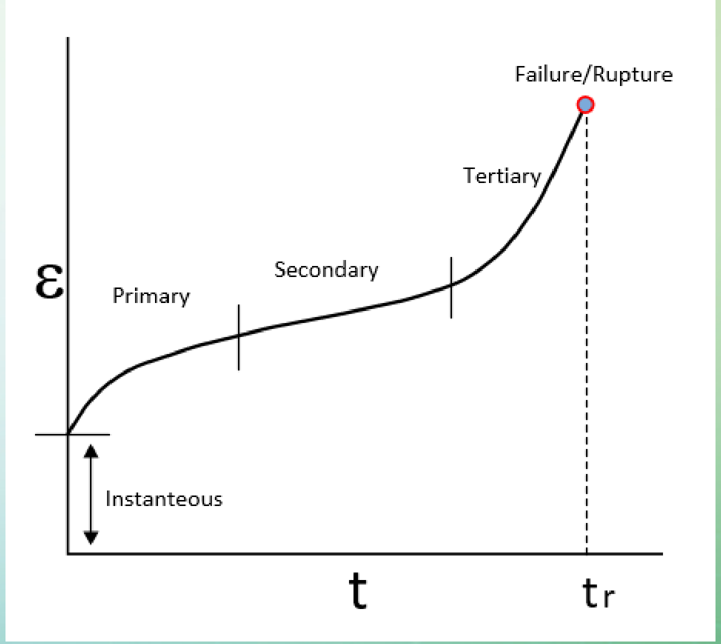
- Tendency of a solid material to continuously deform under a constant stress
- This means a contact current << rated CCC can result in force failure (See MAC Standard)
- Need to understand creep behavior further

Creep - Overview

What is creep?

There are three known regions to a creep curve:

1. Primary: Initial region which typically start upon heating
2. Secondary: Steady state creep region
3. Tertiary: Final accelerate region that is typically the result of microstructure damage



Creep - Overview

- **What affects creep?**
  - High temperatures resulting from high CCC requirements, and/or elevated temperature testing
  - High stresses
  - Grain size/structure of probe material

$$\dot{\epsilon} \propto \sigma^n \left(\frac{1}{d}\right)^p \exp\left(-\frac{Qc}{RT}\right)$$

*P ranges from 2 for very small grains to -2 for large grains

Creep - Overview

- **How does creep effect probes?**
  - Over time, probes can show a **significant drop in gram force**
  - Planarity loss
  - Creep damage can build up over time and result in mechanical failure

Creep-related Reliability Problems

- **Creep tends to slowly deform probes under stress**
  - Probes effectively bend and therefore shorten
  - This also reduces the force
- **Probes tend to suffer from creep in 2 distinct ways:**
  - Internal heating of the probes
  - External applied test temperature
- **Many metals will creep at ~100C very quickly**
  - Lifetime of only hours, enough to pass initial testing but not long-term reliability
  - Pulsing probes with current can further de-rate the probes, easy to reach local temperatures of 250C
  - Even operating the probes at room T with sufficient current pulses can induce creep over time

Objectives

- **Investigate a MEMS style Pd probe material to evaluate the following as they relate to creep**
  - Sensitivity to temperature
  - Sensitivity to probe material
  - Sensitivity to grain size
  - Sensitivity to stress
- **Obtain useful material specific inputs to creep and CCC models**

Experimental Setup

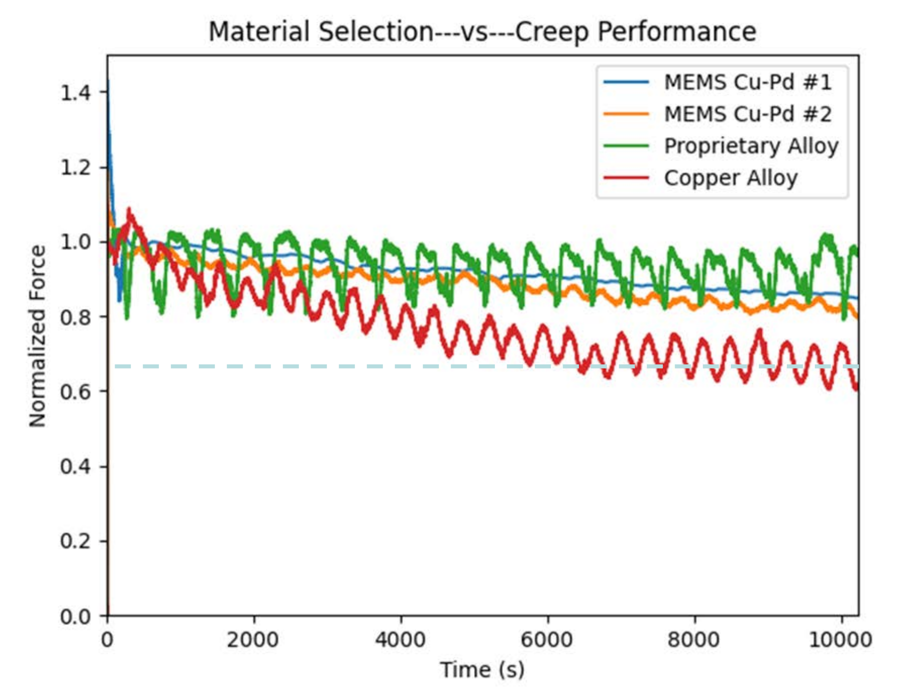
1. Probes are soaked at test temperature for 30 mins

2. Constant OT is applied

3. Probe force is measured continuously for the duration of the test

Material Selection vs Creep Performance -125C

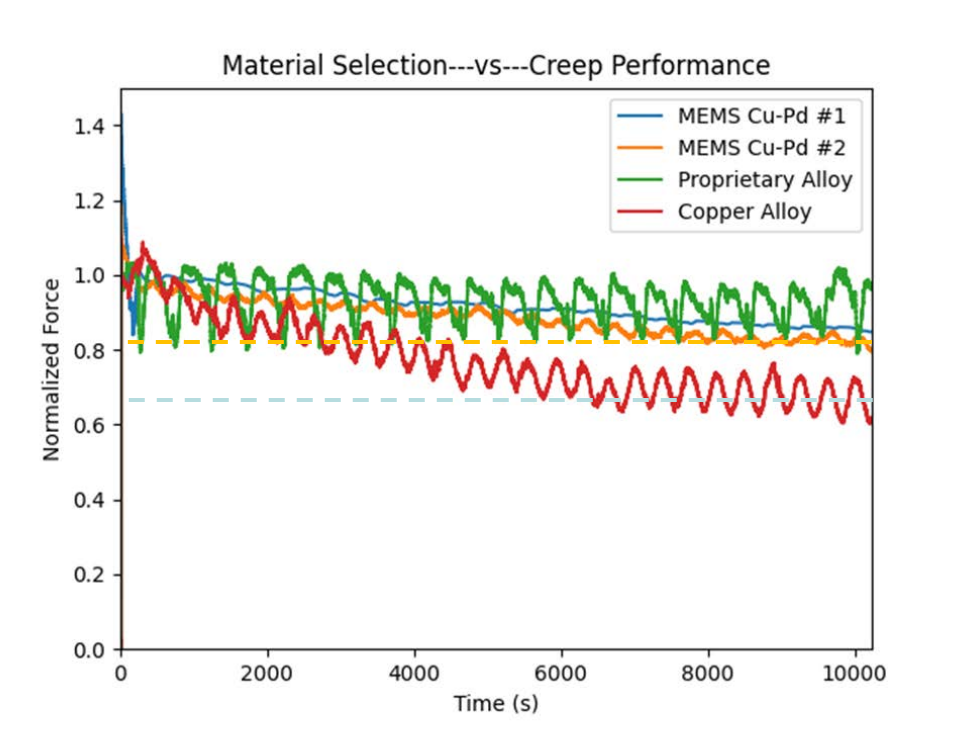
- **Oscillations are due to temperature fluctuation of the test chamber**
- **Force are normalized by each probe's average force reading for the first 500 seconds of the test**



$$\dot{\epsilon} \propto \sigma^n \left(\frac{1}{d}\right)^p \exp\left(-\frac{Qc}{RT}\right)$$

Material Selection vs Creep Performance -125C

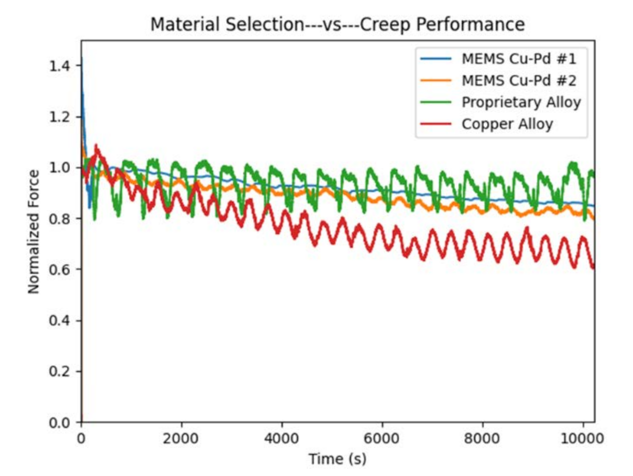
- **All but the proprietary probes exhibit an initial force drop caused by the relaxation of the grain structure at temperature**
- **Proprietary alloy shows no significant drop in the gram force measurement over the duration of the test**
- **Both MEMS samples perform similarly with just under 20% force drop**
- **Copper alloy performed the worst with 35% force drop**

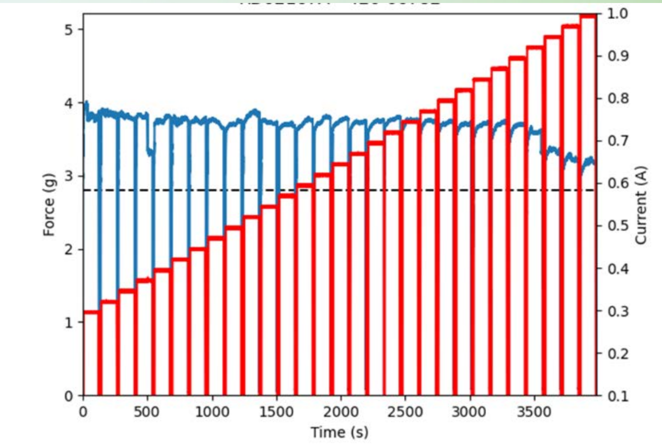


$$\dot{\epsilon} \propto \sigma^n \left(\frac{1}{d}\right)^p \exp\left(-\frac{Qc}{RT}\right)$$

Material Selection vs Creep Performance -125C

- CCC curve shows no obvious sign of creep
- Creep can be masked by the thermal expansion of probes
- Clear need to understand creep behavior in addition to ISMI CCC

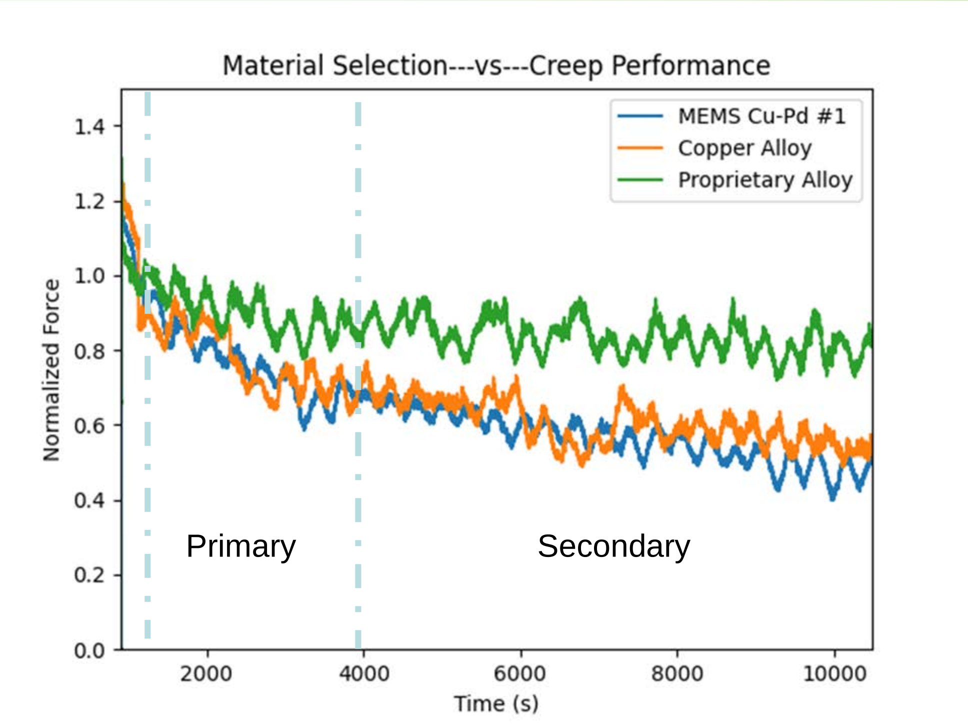




$$\dot{\epsilon} \propto \sigma^n \left(\frac{1}{d}\right)^p \exp\left(-\frac{Qc}{RT}\right)$$

Material Selection vs Creep Performance -185C

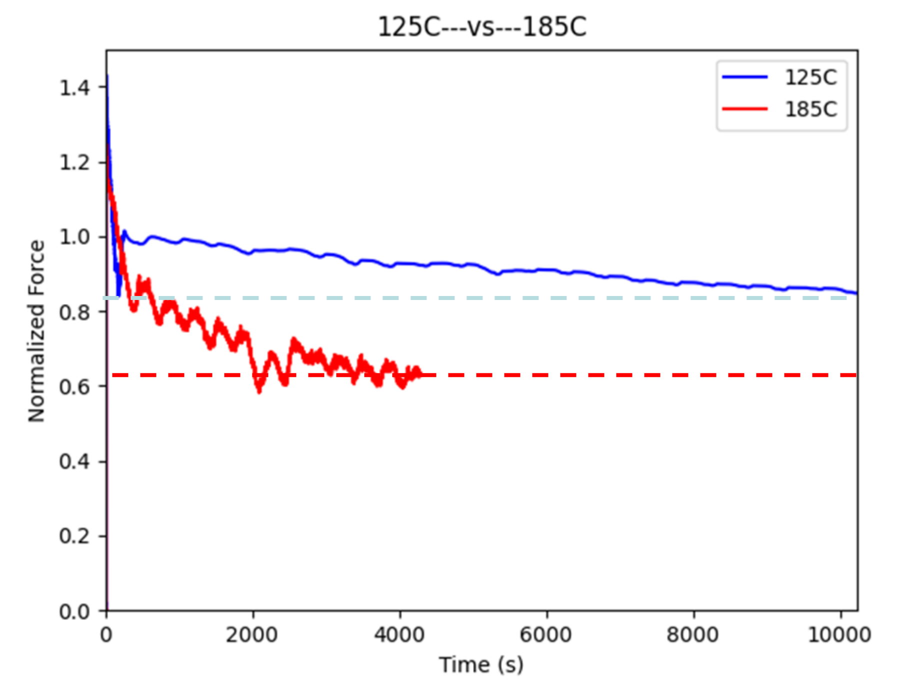
- **Higher temperature accelerated the creep rate for all tested probes**
- **Proprietary alloy shows great temperature stability in the steady state creep region**
- **Unlike at 125C, at 185C, MEMS probes perform similarly to the Copper Alloy**



$$\dot{\epsilon} \propto \sigma^n \left(\frac{1}{d}\right)^p \exp\left(-\frac{Qc}{RT}\right)$$

Temperature Variations

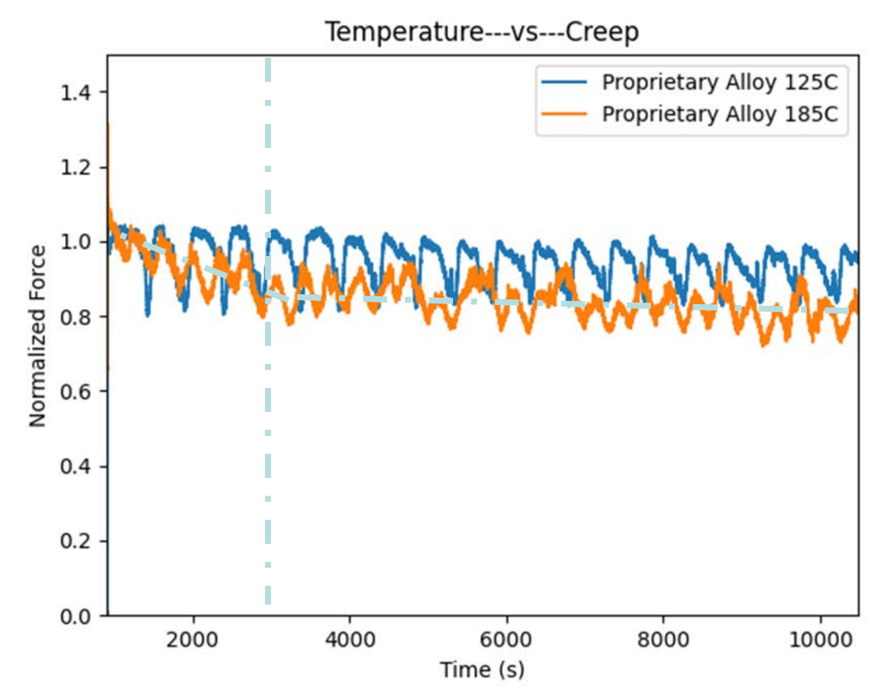
- **MEMS probe show strong dependence to test temperature**
- **Force drops <20% at 125C while at 185C force drops by 40% in the first hour of testing**



$$\dot{\epsilon} \propto \sigma^n \left(\frac{1}{d}\right)^p \exp\left(-\frac{Qc}{RT}\right)$$

Temperature Variations

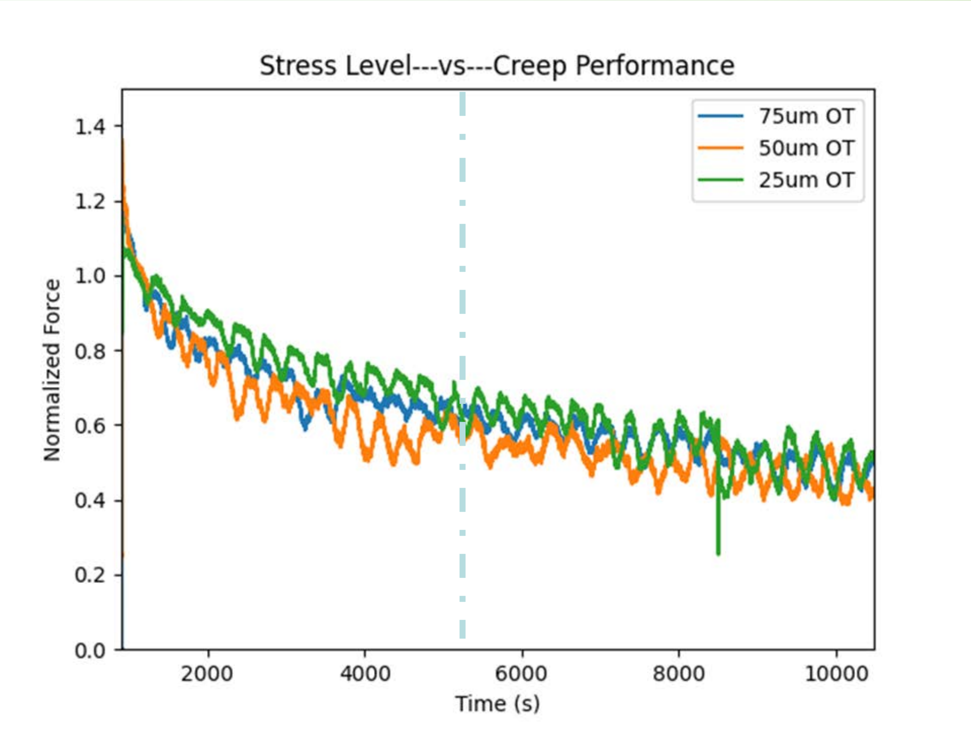
- **Minimal to no instantaneous force drop due to relaxation**
- **Primary creep region is accelerated at 185C**
- **Proprietary alloy exhibits great temperature stability with the probes passing 80% force drop at both temperatures**



$$\dot{\epsilon} \propto \sigma^n \left(\frac{1}{d}\right)^p \exp\left(-\frac{Qc}{\boxed{RT}}\right)$$

Stress Variations

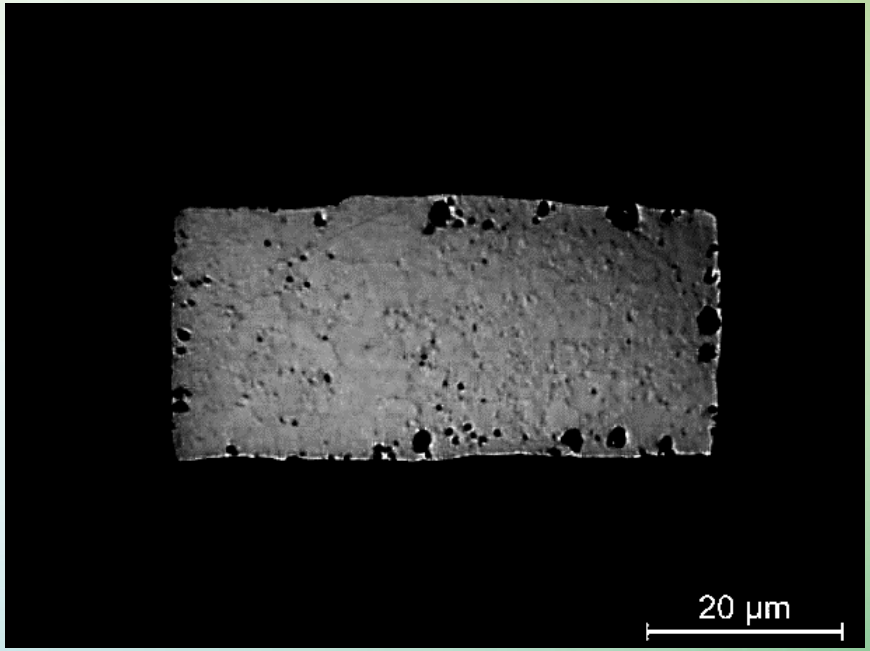
- **The accelerated creep rate shows little to no dependence to stress levels**
- **Weak dependence on stress points to diffusion creep**



$$\dot{\epsilon} \propto \boxed{\sigma^n} \left(\frac{1}{d}\right)^p \exp\left(-\frac{Qc}{RT}\right)$$

Heat Treatments/Grain Size Variations

- **Electro deposited parts typically have very small grain sizes that have detrimental effect on their creep performance**
- **Grain growth can be achieved by heat treating parts at temperatures higher than their recrystallization temp**
- **Metal diffusion can happen at a rapid rate at these elevated temperatures**



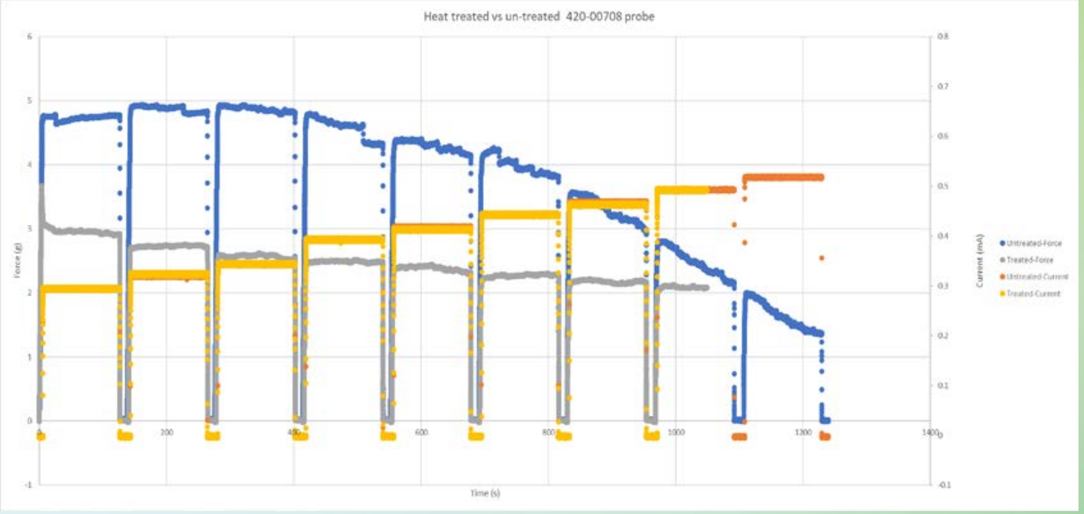
$$\dot{\epsilon} \propto \sigma^{n} \left(\frac{1}{\enclose{circle}{d}}\right)^{p} \exp\left(-\frac{Qc}{RT}\right)$$

Grain Size vs Creep Rate

- Here annealing the parts resulted in more step like CCC curve

- While altering the grain structure can result in an undesirable reduction of other mechanical properties such as yield strength

- No significant force drop during the 2 minutes hold



$$\dot{\epsilon} \propto \sigma^n \left(\frac{1}{d}\right)^p \exp\left(-\frac{Qc}{RT}\right)$$

Conclusions

- **Dominant factors for probe cards**
  - As the industry pushes for higher temperature test conditions, creep is becoming a more significant source of failure.
  - Probe materials must have balanced characteristics to meet the Force, CCC, and Hot Test requirements.
- **Possible methods of improving creep behavior**
  - Temperature management, heat treatments to alter grain size, and low stress designs.
- **Design rules**
  - Further work required to determine if lower stress designs can mitigate creep in certain materials.
- **Effects on ISMI CCC testing results**
  - Some probe materials creep so quickly, that the 20% force reduction fail criteria can be met in a matter of minutes.
  - This results in ISMI CCC ratings that are significantly higher than what could be used for real wafer test conditions.

Future Work

- Establish a standard for evaluating creep behavior of probes in a way that indicates their lifetime and usefulness in various test conditions.
- Design test methodologies to evaluate materials in bulk form, to study the inherent properties of the materials that are not dependent on the geometric design of the probes.
- Determine useful parameters to the creep equations to be used as inputs in predictive modeling.