

A Statistical Assessment of Zener Diode Behavior Using Functional Data Analysis

Xiaoxia Champon, David Angeles, Thomas Buchheit, David Canfield,
J. Derek Tucker, Jason Adams

Sandia National Laboratories, North Carolina State University, The Ohio State University



Sandia
National
Laboratories

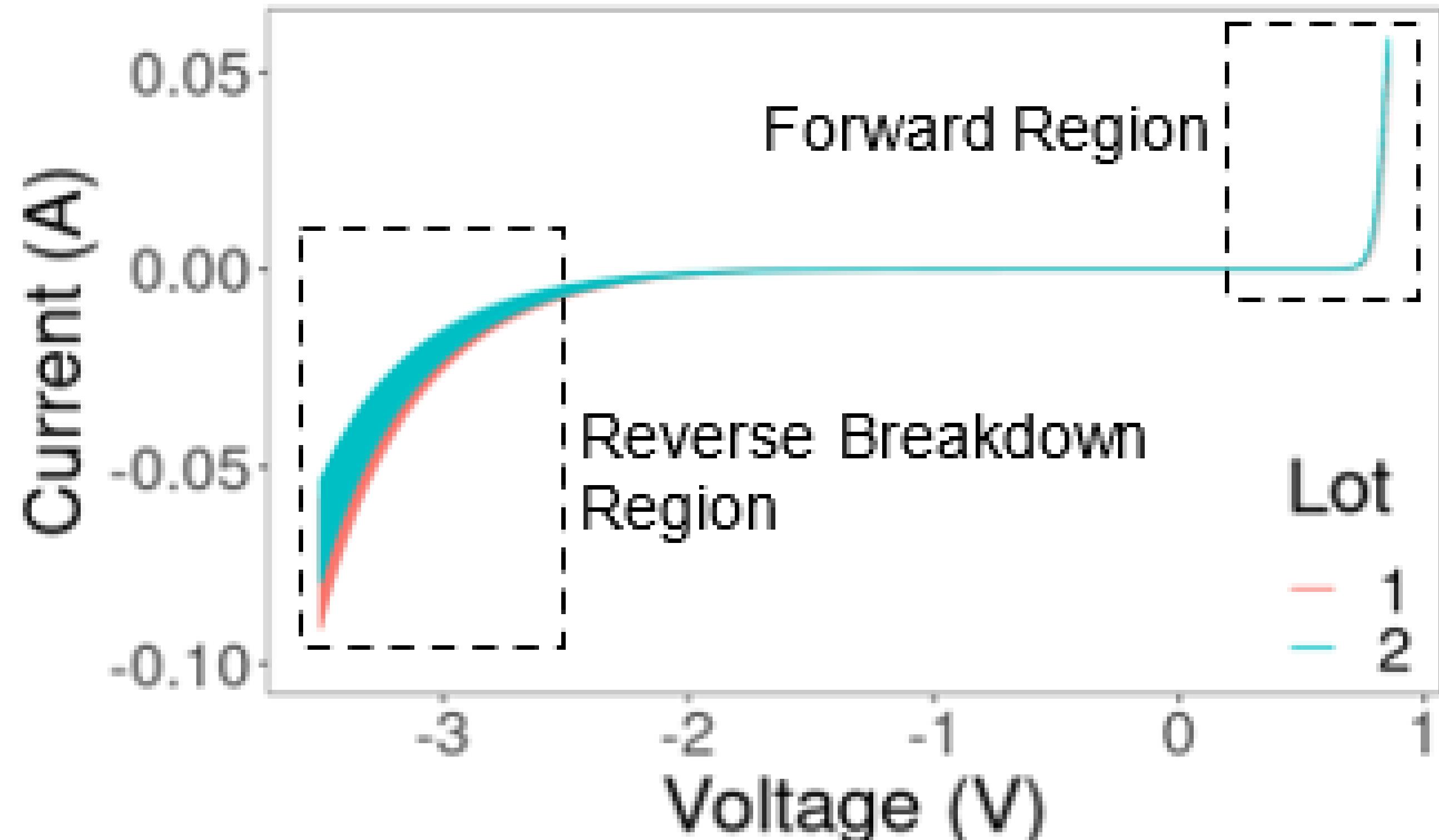
SAND2023-12389C

Abstract

This poster presents an assessment of electrical device measurements using **functional data analysis (FDA)** on a test case of Zener diode devices. We employ three techniques from FDA to quantify the variability in device behavior, which is primarily due to production lot and demonstrate that this has a significant effect in our data set. We also argue for the expanded use of FDA methods in providing principled, quantitative analysis of electrical device data.

Introduction

- The principled statistical analysis of electrical device data can yield important insights regarding device technology and manufacturing.
- Our **Data** come from 95 MMSZ522BT1G Zener Diodes from production Lot 1 and 98 from Lot 2.
- Our **Goal** is to investigate whether device behavior differs across production lots and to quantify the variability among the devices.
- Our **Method** is to use Functional Data Analysis (FDA) to provide a formal assessment of the behavior of these devices

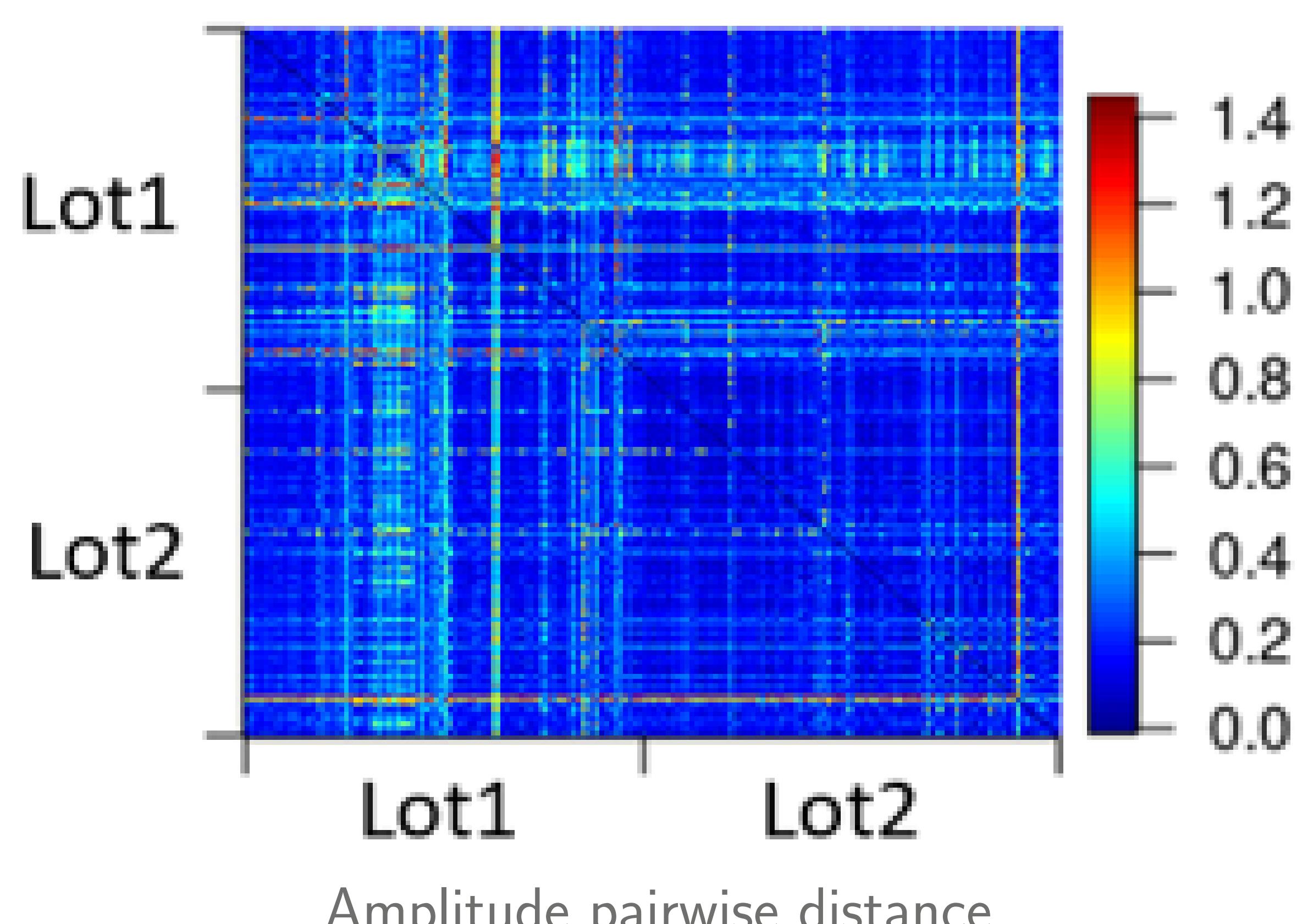


I-V curves from Zener diodes colored by production lot

Functional Data Analysis

- Functional Data: Functional data vary continuously across an independent variable.
- Current-voltage (I-V) sweeps, the electrical measurements which characterize the operational behavior of these parts, are functional observations.
- Denote $C_{ij}(V_{ij})$ as the observed current curves from device i at voltage j where $i = 1, \dots, 193$ and $j = -3, \dots, 3$.

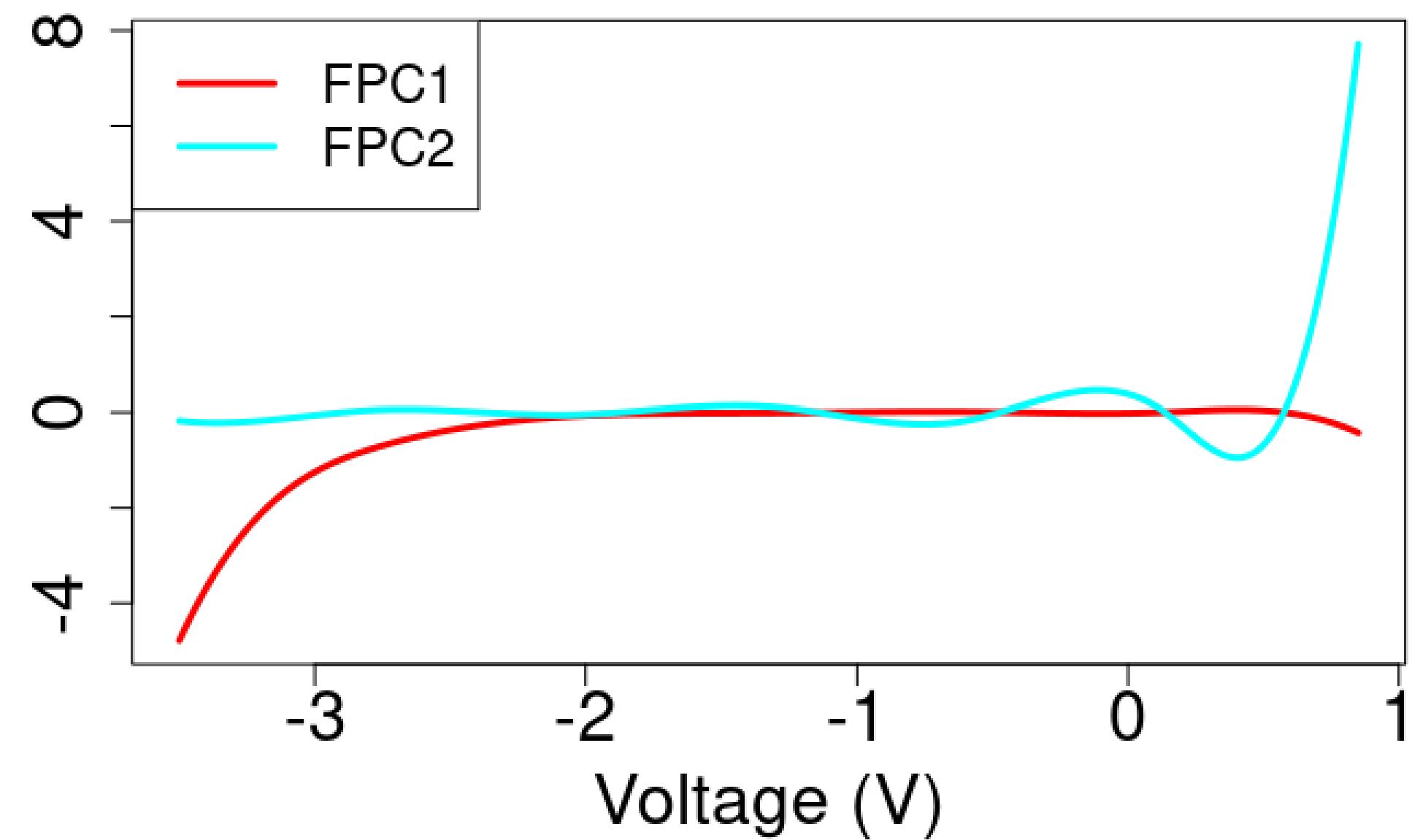
Elastic Amplitude and Phase Distances



- Amplitude and Phase Distances: The characterization of two sources of variability in FDA are amplitude, or y-axis, and phase, or x-axis, distances between the functions.
- A nearly uniform matrix is expected if there's no lot difference.
- There is a subset of devices in production Lot 1 whose I-V curves differ substantially from the rest of the devices.

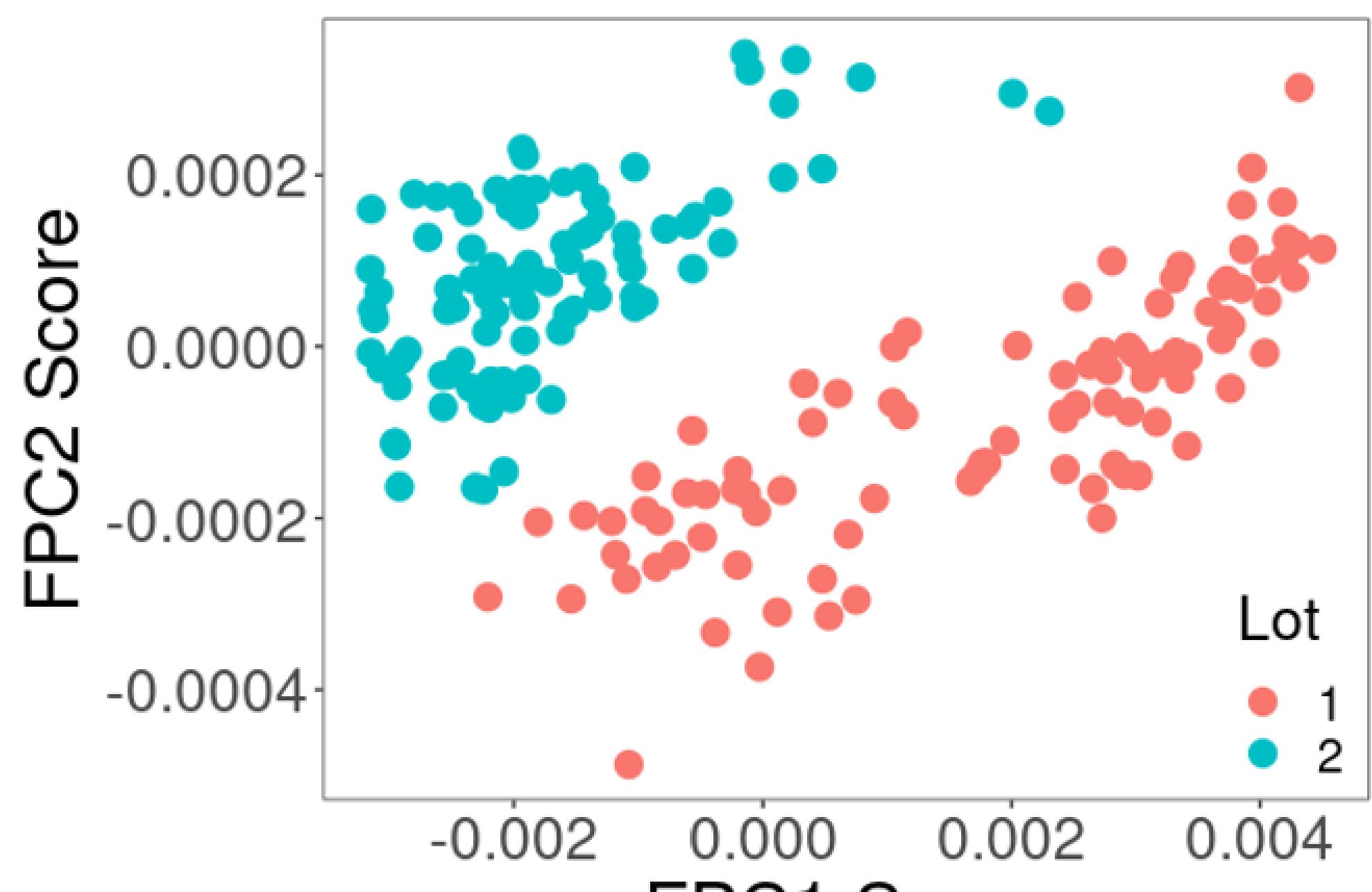
Functional Principal Components Analysis (FPCA)

- FPCA reduces the dimension and maximize the variance along the FPCs.
- The first component (FPC1) describes the variability of the devices in the reverse breakdown region. The FPC2 describes variability in the forward region.



Functional principal components

- Relative to production Lot 1, devices from production Lot 2 tend to have smaller absolute current values in the reverse breakdown region while having larger current values in the forward region.



Functional principal component scores colored by production lot

Functional on Scalar Regression

	Estimate	Standard Error	p-value
Intercept	-0.007	< 0.01	< 0.0001
Lot 2	0.002	< 0.01	< 0.0001

- The mode: $C_i(V_{ij}) = B(V_{ij}) + B_0 + B_1 \text{Lot}_i + \text{err}_i(V_{ij})$ where i is the device and j is the voltage value.
- $R^2 = 97.5\%$
- The average current in Lot 2 is 0.002 unit more compared to Lot 1.

Summary and Future work

- Three FDA techniques have uncovered insights about the effect of production lot on device behavior.
- We have quantified the effect of production lot on device behavior and assessed the variability among the devices.
- Future work can investigate the effects of aging on the devices that have been subjected to an aging condition and measured over time.
- FDA can provide principled quantitative analysis and useful insights for challenging data sets.
- We advocate for the expanded application of FDA methods in this community.