SAND2013-10464C

# Discovery of Hidden Dimensions in Information Space and Ultra-High Density Memory

**Andrew J. Lohn*, Patrick Mickel, Matthew Marinella**
**Sandia National Laboratories, Albuquerque, NM**
***ajlohn@sandia.gov**

## Introduction

- **Moore's Law has resulted in truly remarkable information density but scaling is both incredibly expensive and extremely challenging**
- **We developed a technique to store orders of magnitude more data per device using only standard resistive memory devices.**

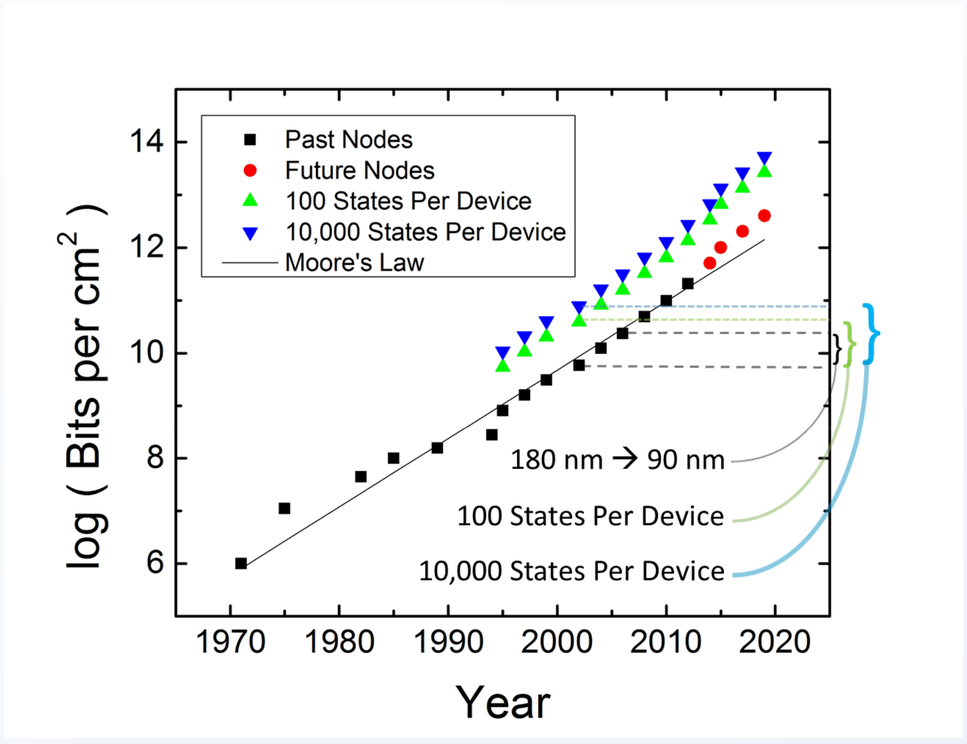


**Fig 1: A logarithmic plot shows scaling of bit density for Moore's Law and Multi-dimensional Information Space**

- **At the level we have already demonstrated, we can add ~7 years to Moore's law for memory and we expect 10 years is reasonable.**
- **The approach is based on expanding information storage into higher dimensions by electrically tuning the filament properties.**

## Hidden Dimensions

- **Digital memory is 0-dimensional like a point in space. Some memories are now 1-dimensional over a small range (i.e. Resistance = 1,2,3).**

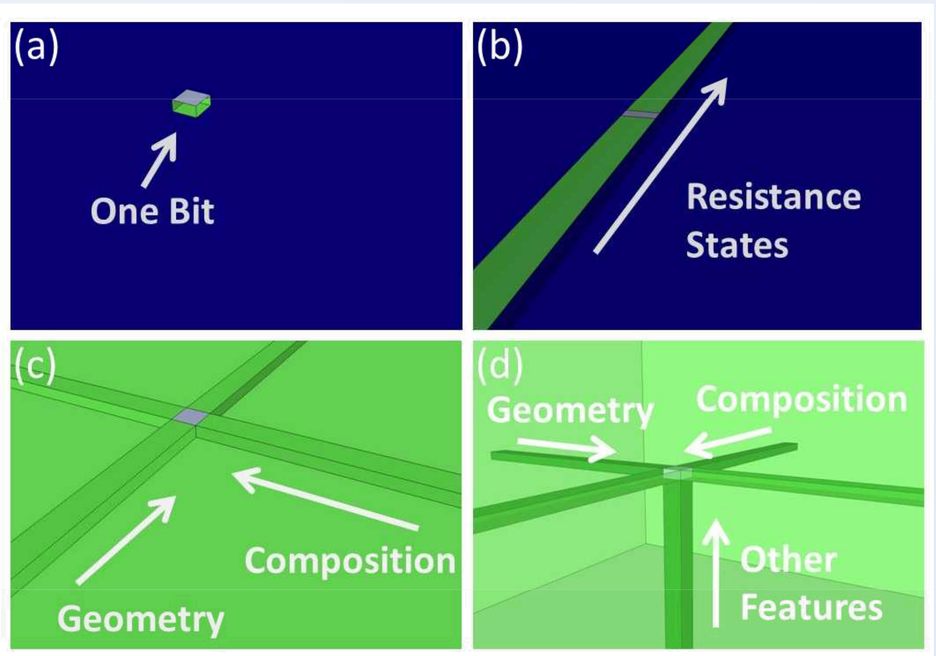


**Fig 2: Information space depicted for (a) digital, (b) mulit-level cell, (c) 2-dimensional, and (d) many-dimensional devices.**

- **Since resistance depends on radius and conductivity, and we can control both, we can make two dimensional information space.**

## Reading and Writing: 2-D

- **Positive polarity sets the radius and negative sets the conductivity**
- **Power and resistance are more useful coordinates than I-V.**

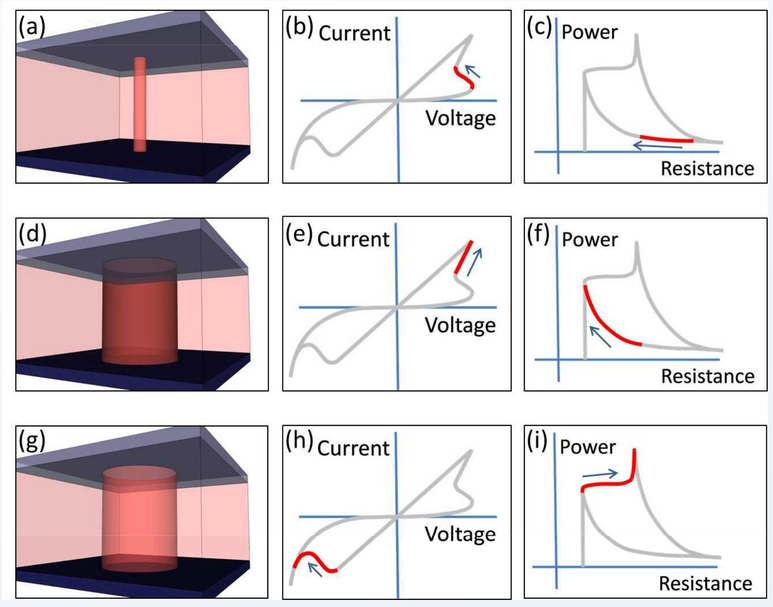


**Fig 3: The radius and conductivity can be controlled separately by selecting electrical polarity. Power-resistance are particularly useful coordinates.**

- **To read the state, the resistance is measured, then the power required to change resistance is measured, giving 2 dimensions.**

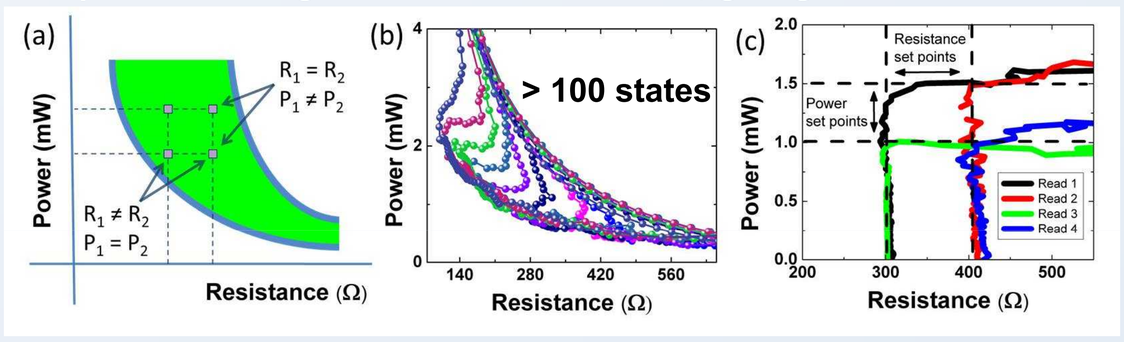


**Fig 4: 2-dimensional information space in power-resistance coordinates is depicted and experimentally demonstrated for write and read.**

## The Third Dimension

- **By changing the geometry away from cylinders it is possible to make at least one more dimension.**

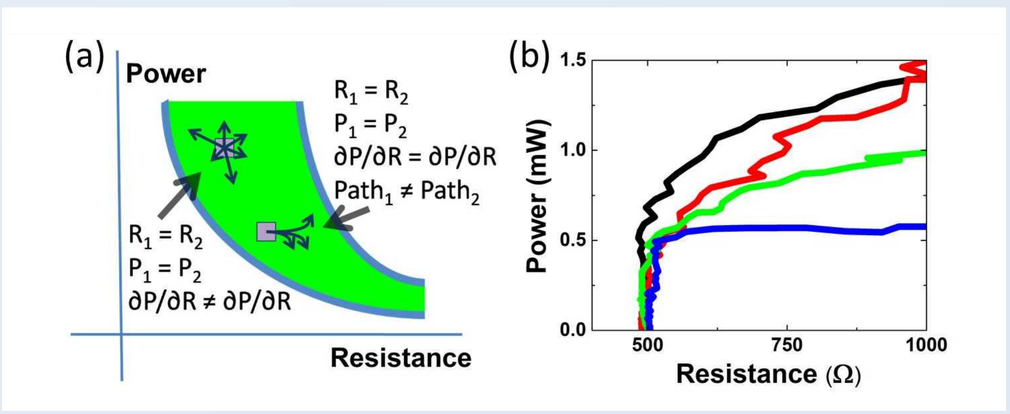


**Fig 5: A third dimension (and probably more) exists using the slope at every point in power-resistance space.**

## Summary

- **Hidden dimensions add ~ 7-10 years to Moore's Law for memory.**
- **This approach can be implemented rapidly because it uses only standard devices already in development.**

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.