

# LEMELSON-MIT

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*\$15,000 "Use it!" Lemelson-MIT Student Prize Graduate Winner  
Electron Microscope Pixel Array Detector (EMPAD) and  
Low-Cost airSTEM*

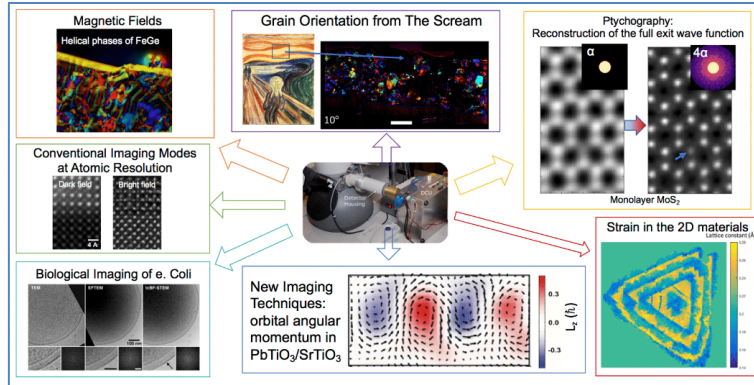
**The Challenge:** Scanning transmission electron microscopy (STEM) is an imaging tool for analyzing materials at the very tiniest of scales (the micron, nano and atomic levels). STEM is typically used to visualize structures at the atomic level, which can be beneficial in applications ranging from the protein signatures of Alzheimer's to the arrangement of atoms within the smallest part of a computer chip. However, current detectors used in STEM are limited in their detection, where only a small part of the signal can be extracted – here, scientists and researchers only get one piece of the puzzle.

To improve this traditional technique, new detectors must be developed that can capture more than just a direct image of matter and where the *saturation* of the image is a key factor. Using STEM imaging in diffraction mode, many factors can be analyzed all at once, such as the structural, chemical, electrical, optical, and magnetic properties. The current electron detectors available for electron microscopes discard much of this extra information due to their slow speeds and limited dynamic range.

In a related challenge, with conventional scanning electron microscopy (SEM), biological samples often need to be put through chemical changes as preparation for being imaged in high vacuum. This introduces sample artifacts that could be misinterpreted as false positives while enhancing the contrast of the sample's image. In addition, this prevents the specimen from being imaged in its natural environment and does not allow for a true viewing of the sample as it actually exists. Tweaks to this SEM method, such as environmental scanning electron microscopy (ESEM), have opened the door for imaging of specimens in a gaseous environment, yet that technique still requires a specimen chamber, which slows down the time it takes to image a sample. The current airSEM product by b-Nano presents another solution to this issue, as it operates in air (not vacuum) and *without* a specimen chamber, using a transparent window that separates the vacuum from air. However, this system on its own without a transmission detector still lacks the sensitivity needed for extremely thin specimens like graphene.

**The Solutions:** Kayla's primary invention is an electron microscope pixel array detector (EMPAD), a fast, highly-efficient diffraction detector for electron microscopes. The detector is designed to recapture and harness the missing information from samples that existing conventional electron diffraction detectors fail to provide. The EMPAD is used in STEM mode and is novel in that it can collect all of the scattered electrons at each point in the scan with high dynamic range – the EMPAD can detect 1 or 1 million electrons without saturating the image. This is comparable to someone taking a selfie with the sun in the background and being able to see an unsaturated image of the person and the sun with all its sunspots, both in perfect detail.

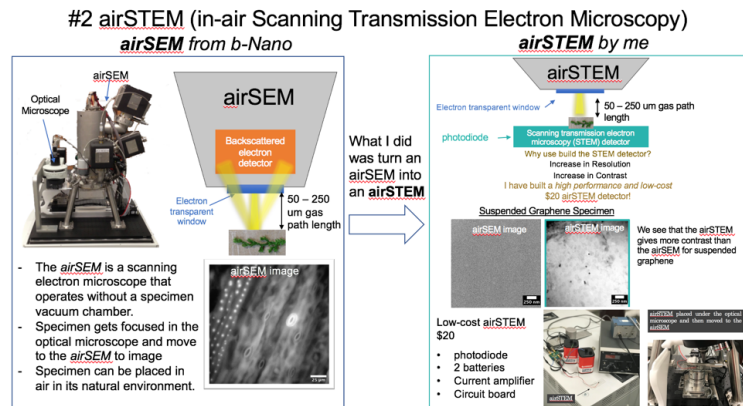
The EMPAD is able to extract an unprecedented amount of information from the specimen that was previously unobtainable using only one detector, such as thickness, strain, tilt, octahedral rotations, polarity, atomic fields, and long-range electromagnetic fields.



Given this capability, the EMPAD is a universal detector that can replace at least five different commonly-used imaging detectors that are specifically designed for use in electron microscopes. Due to the variety of samples that can be imaged with the EMPAD alone, its results can also greatly contribute to fields such as medicine, technology, and even art. Applied correctly, EMPAD could help lead to faster computers, cheaper electric cars, and detailed conservation of historic paintings by providing a more in-depth depiction beyond the structure.

Kayla's secondary invention, the airSTEM, is a high-performance and low-cost STEM detector that works in air and without need for a vacuum chamber for the specimen being examined within a microscope. Kayla created it by modifying an airSEM, which only detects electrons scattered from the surface of the sample, into an airSTEM, which can detect

electrons transmitted through the sample. The airSTEM detector costs only \$20 to make and is capable of capturing as thin as a single layer of atoms and biological membranes that are too difficult for an airSEM to view. Using graphene (a single sheet of atoms) as a test, Kayla compared the imaging results of her airSTEM with the airSEM images, and found that her low-cost airSTEM gave far better contrast.



**Commercialization:** Kayla's EMPAD is already impacting the scientific and invention communities. It has been exclusively licensed for scanning transmission electron microscopes to Thermo Fisher Scientific, whose electron microscopy division has commercialized the EMPAD, selling it to early adopters of the technology. The electron microscopy market is worth \$4 billion annually, and while the EMPAD has already affected this market, its impact can extend beyond just the electron microscopy market, given the variety of fields that it can be used in, from computers to automobiles to art conservation.

Kayla's secondary invention has not yet been commercialized. Typical electron microscope detector prices can range from \$1K-\$10K, whereas Kayla's airSTEM only costs \$20, providing a strikingly inexpensive way to change an airSEM into an airSTEM. The airSTEM can also be modified to make it more compatible with conventional SEMs, thereby expanding the market. The airSTEM is well suited for biological imaging in hospitals for rapid medical diagnostics, and could also be used as a teaching tool for high school physics classes or undergraduate laboratory courses where students could build their own airSTEM and test the detector, from which they would learn about electron scattering physics.