

NDnano Summer Undergraduate Research 2018 Project Summary

1. Student name & home university: Gavin Inglis, University of Notre Dame
2. ND faculty name & department: Dr. Sergei Rouvimov, Director of TEM, Electrical Engineering
3. Summer project title: Image Processing and Data Analysis in Transmission Electron Microscopy
4. Briefly describe new skills you acquired during your summer research:

Technical skills I learned:

- Finding periodicity vectors from a radon transform projection and standard deviation of projection at vector angles
- Interpolation of image data to include more pixels and data points
- Use of mathematical algorithm to average pixel values based on found periodicity vectors

I learned how to approach problems that were new or foreign to me. I learned how to explain my code not only through comments but also through meetings with Dr. Rouvimov.

5. Briefly share a practical application/end use of your research:

Our research has practical applications in the improvement of TEM images, especially images with the “.tif” file format. Our research greatly improves the clarity and resolution of these images.

6. 50- to 75-word abstract of your project:

Transmission electron microscopy is one of most advanced metrologies in materials science, and the fast and accurate analysis of TEM data is a key for success in delivery of novel results. This research focuses on developing scripts written in MATLAB to process images and analytical data to get the most accurate results in TEM using periodicity vectors and an intensity averaging algorithm.

7. References for papers, posters, or presentations of your research:

X. Sang and J. M. LeBeau. *Revolving scanning transmission electron microscopy: correcting sample drift distortion without prior knowledge*. *Ultramicroscopy*, 138:28-35 (2014)

Dr. LeBeau Research Group: <https://www.mse.ncsu.edu/lebeau/>

A crucial aspect of science and technology is the development of advanced software that allows fast data acquisition. This includes both online and offline data processing, improvement of signal-to-noise ratio, and insight into sample structure. Such software development is important for electron microscopy because it enhances the quality of the data and extracts valuable information. Scanning Transmission Electron Microscopy (STEM) is one of the fastest growing techniques for atomic resolution imaging of crystal structures to provide information of their composition. Reduction of noise and improvement of image quality without creating artifacts is an ongoing issue in the field of ultramicroscopy.

The Dr. James M. LeBeau group at NCSU has published several papers focusing on STEM data processing¹ that significantly improve the quality of their images. One of their papers² described a MATLAB program that improved the quality of STEM images. The results of the paper were very influential to our project. Dr. LeBeau's webpage has a MATLAB program that demonstrates how to measure and correct image distortion. His research group's program was a useful starting point for our own MATLAB code that could be used to correct experimental images that TEM users collected at NDIIF by FEI Titan 80-300.

Because developing such sophisticated code on MATLAB requires a lot of experience, we invited Cristobal Alessandri, an electrical engineering graduate student, to participate as a consultant to our project. Cristobal provided useful recommendations in writing this code and helped with debugging the program. Our program consists of two key steps: finding the vector(s) of periodicity and averaging across the image using a lattice created by the vector(s) of periodicity. The initial part of our code is similar to that of the NCSU program. It begins by analyzing the image projections in angles from -90° to 90° , finding the standard deviation of this projection, and calculating angles at which there is drift or distortion from this standard deviation. Using the angles described above and the magnitudes of their corresponding vectors, our algorithm averages across a matrix given two vectors. The algorithm works so long as the image is resized; if it is not resized, MATLAB will give an error stating that the program is not using integers to index the image because the periodicity vectors are floating point numbers. The approach that was used in our algorithm employed interpolating the image, which increases the dimensions of the image while maintaining the composition of the original image. Interpolating the image allowed us to convert an image of dimensions (N,M) into an image of dimensions (N*factor, M*factor), where the factor is a scalar. If both the image and the vectors are scaled and rounded, the program can call correct integer indices of the image. The equation for the averaging algorithm and its implementation in our MATLAB script is shown below:

```

A(x,y)
= A(x,y) + B(x + x0 + n * r1(x,y) * factor + m * r2(x,y) * factor, y + y0 + n * r1(x,y) * factor
+ m * r2(x,y) * factor

for i = 1:new_imgX
    for j=1:new_imgY
        new_img(i,j) = 0;
        for n = 0 : N
            for m = 0 : M

new_img(i,j)=new_img(i,j)+(img_double(i+round(xo+n*x2*factor+m*x1*facto
r),j+round(yo+n*y2*factor+m*y1*factor)));
                end
            end
        end
    end
end
new_img_8 = uint8(new_img/(N+1)/(M+1));

```

¹ <https://www.mse.ncsu.edu/lebeau/>

² X. Sang and J. M. LeBeau. *Revolving scanning transmission electron microscopy: correcting sample drift distortion without prior knowledge*. Ultramicroscopy, 138:28-35 (2014)

Figure 1. SrTiO₃ crystal

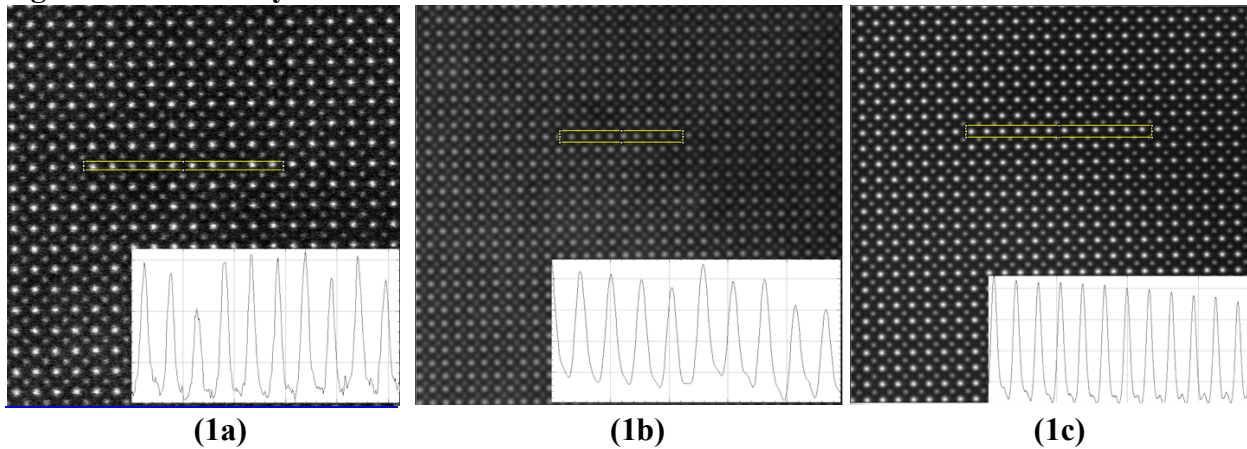
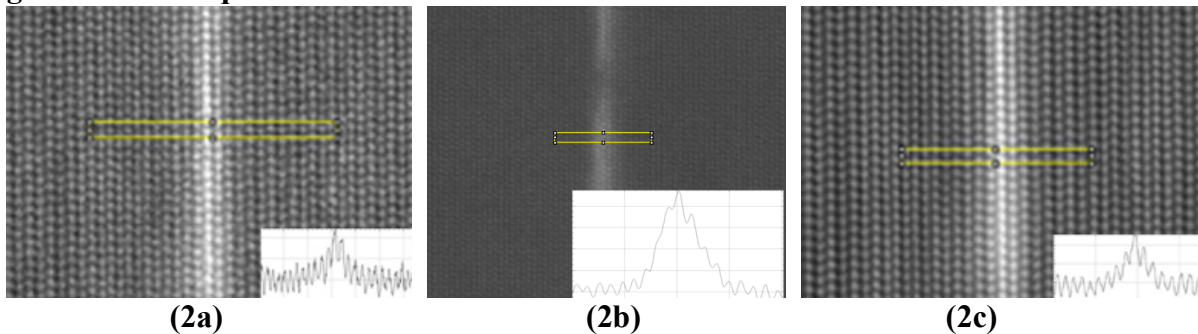


Figure 2. AlGa_N quantum well embedded in AlN



Figures 1 and 2 show two types of STEM images: (1a) SrTiO₃ crystal taken on Temis Z at FEI NanoPort in Hillsboro and (2a) AlGa_N quantum well embedded in AlN matrix taken on FEI Titan 80-300 at NDIIF. Even though the SrTiO₃ STEM image (Fig. 1a) that was taken by aberration corrected STEM with monochromated electron source has much better contrast, it still contains a lot of noise due to the physical properties of the detector. For comparison, the images are shown with a Gaussian filter of sigma four (1b, 2b) and after processing in our program (1c, 2c). The plots are from a program called ImageJ which is specialized for analyzing these kinds of images. The profile of the improved image shows round curves, which are much less noisy than the jagged curves of the original image's profile, as well as higher contrast between low and high intensities.

I am grateful to Dr. Rouvimov and Cristobal for their help and guidance, and I am thrilled with our results.