On the improvement of sapphire surface image analysis via 2-dimensional Fast Fourier Transformation (2D-FFT)

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Accurate determination of sapphire surface features like terrace width, step height, terrace orientation and offcut angles is critical for a detailed understanding of MOCVD growth mechanisms for 2D materials. Conventional analyses typically rely on one-dimensional Fast Fourier Transform (1D-FFT) evaluation of individual line profiles extracted from atomic force microscopy (AFM) images. While effective, this approach is sensitive to noise, local defects, and scan-direction.

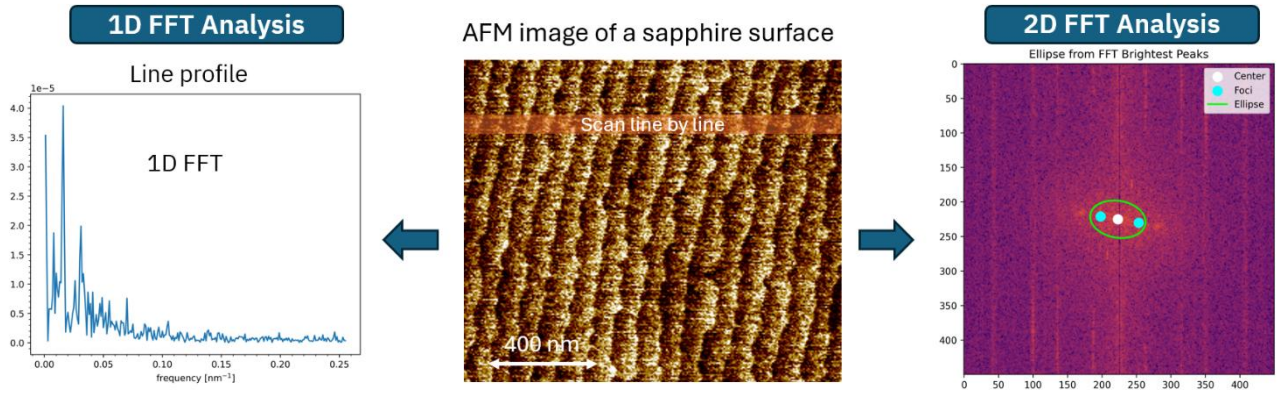

Figure 1: AFM image of a sapphire substrate surface after a pre-annealing step at high temperatures (middle). The left and right images show a 1D-FFT and 2D-FFT image analysis approaches, respectively.

Here, we introduce a direct two-dimensional FFT-based method (2D-FFT) that exploits the full spatial information of the AFM image. In the 2D frequency domain, periodic terrace structures manifest as distinct localized peaks. Terrace width is determined from the radial position of these peaks, while terrace orientation is obtained directly from their angular distribution. In contrast to 1D FFT analysis, the 2D approach inherently integrates global surface information, eliminating the need for post-processing averaging. Periodic features generate sharp spectral peaks, whereas noise and non-periodic defects are broadly distributed in frequency space, leading to enhanced robustness and orientation independence. Validation with synthetic periodic surfaces confirms the reliability and noise resilience of the method. Overall, the proposed 2D-FFT framework provides a stable and physically representative alternative for extracting terrace parameters from AFM data.