Transmission Electron Microscopy (TEM) provides powerful techniques for understanding various information of materials at very high spatial resolution, including morphology, size distribution, crystal structure, strain, defects, chemical information down to atomic level and so on. All the information that TEM can give to us are from electron-sample interaction. The transmitted electrons that have passed through the thin sample are detected to form images, which is the reason to call it “transmission” electron microscopy. In order to allow electrons to transmit through the sample, TEM sample must be very thin (typically, sample thickness is less than 200 nm, depending on the composition of sample and the expected information from TEM characterization).

There are many techniques in transmission electron microscopy, which can give you different information about your samples. Some techniques are listed below:

1. **Selected-area electron diffraction (SAED)**. One of the two basic operations of TEM imaging system, i.e. diffraction mode and imaging mode. For SAED, a selected area aperture is inserted into the image plane to virtually select an area from the sample to form diffraction pattern. SAED can be used to identify crystal structures, nanowire growth direction, tell crystallinity and set up conditions for dark field imaging.
2. **Bright filed (BF) TEM**. BF images are formed by the direct-beam (transmitted beam) electrons, only very few scattered electrons can pass the aperture to contribute to the imaging.
3. **Dark field (DF) TEM**. An objective aperture is inserted into the back focal plane (where diffraction pattern is formed in the reciprocal space) to select scattered electrons. Typically, a specific diffracted beam (single crystalline) or a portion of a diffraction rings (polycrystalline) can be used for DF imaging. DF images can usually give information on nanocrystal size distribution and crystalline defects, such as stacking faults, twining, and dislocations.
4. **High-resolution TEM (HRTEM)**. The imaging mechanism of HRTEM is phase contrast, which uses the interference of the transmitted beam and diffracted beams to form images at atomic level. HRTEM is useful for the imaging of atom arrangements in projection. This technique normally requires very thin samples (less than 15 nm in thickness, as thin as possible). The interpretation of HRTEM images is always challenging.
5. **High angle annually dark field (HAADF) – STEM imaging**. HAADF-STEM imaging collects incoherently scattered electrons at high angles to form images, which gives contrast dependent on atomic number and specimen thickness. It is also called Z contrast.
6. **Energy-dispersive X-ray spectroscopy (EDS)**. EDS can provide compositional or chemical characterization. Our Titan with ChemiSTEM technology can collect X-ray much more efficiently. The four windowless silicon drift detectors (SDDs) can provide a solid angle of 0.7sr. X-FEG can provide 5 times more electrons compared to a conventional Schottky FEG source. Overall, it can collect up to 10 times X-ray compared to conventional single-SDD.
7. **Electron energy loss spectroscopy (EELS)**. When electrons pass through the sample, some electrons are getting inelastically scattered and results in both energy loss and a change in momentum. These energy losses are characteristic for the elements in the sample. A typical EEL spectrum contains zero loss peak, low lose and core loss regions. Zero loss peak is formed by elastically scattered electrons with zero energy loss and electrons that do not interact with the sample, from which we can get the sample thickness (also need the sum of inelastically scattered electrons). Low loss region is formed by electrons with low energy losses, which can

give information on sample optical properties. Core lose region is formed by electrons with energy losses by ionization of core shells, which can provide information on elemental composition and concentration, as well as bonding/valence state. Very thin samples (less than 50 nm in thickness) are required for EELS analysis.

8. **Energy-filtered TEM (EFTEM)**. Only electrons with particular energy losses ("energy windows") are chosen by energy slit to form images. Since the energy losses are characteristic of the elements in the sample, EFTEM can be used for elemental/chemical mapping. It can also be used to improve the contrast in images and diffraction patterns by removing inelastically scattered electrons.
9. **3D electron tomography**. (S)TEM image is basically 2D projection of 3D object. A special tomography holder is used for tilting sample over a wide angular ranges (for example, -70 degrees to +70 degrees). 2D projection images are taken at each tilting angles. Hundreds of 2D images are aligned and reconstructed to 3D visualization of the imaged object by using back-projection methods. In addition, STEM-EDS tomography can provide chemical information in 3D morphology.