Literature Study

2008 - Electron energy-loss spectroscopy in the Transmission Electron Microscope (TEM)

Information in the paper includes:

1. **The workings of an TEM**
   The transmission electron microscope works by accelerating electrons and shooting them through a material, this results in electrons with different velocities which will be separated into a spectrum by a magnetic prism. This spectrum then falls upon a detector.

2. **The physics of an Electron Energy-Loss Spectrum**
   The aforementioned spectrum is a superimposed spectrum of smaller spectrums which are the result of different interactions between the sample and the shot electrons.

   The paper continuously talks about a "differential cross section" expressed by σ which is a measure of probability for scattering to occur.

   Elastic Scattering
   This type of scattering transforms energy from the shot electron to the sample, its angular distribution is quite narrow. The scattering angle is a result of how close the shot electron passes the nucleus of an atom. These angles are discretised and called Bragg angles, (I assume this relates quite closely to the studied material for Solid State Physics were this was due to the repeating lattice). The scattering angles can be widened due to extra phonon scattering but these energies are to low to be measured in a TEM-EELS system. Probability is given by $d\sigma/d\Omega$ where Ω is the absolute angle.

   Inelastic Scattering
   Coulomb interaction gives rise to this type of scattering. Due to the similarity in mass (probably talking about effective masses m^*) between the projectile (shot electron) and target (electron bound to sample) the energy loss of the shot electron is quite large, $1...10^2 eV$. Probability is given by $d^2\sigma/d\Omega dE$.

   Plasmon excitation
   A phenomenon that arises because outer-shell electrons are weakly bound to the atoms but enjoy a strong interaction by electrostatic forces and thus form an energy band. When a high energy electron travels trough a material at a speed higher then the Fermi-speed in that material the electron pushes away the surrounding electrons which leaves a relatively positive wake behind, this creates a net force decelerating the speeding electron. *Interesting*.

   The energy loss is a result of plasmon-loss event which are related to the mean free path of an electron. This quantity can be used to estimate the thickness of the material (Here).

   Surface plasmons and radiation loss
   Before the electrons even reach the specimen they polarise its entire surface, in case of a conducting sample longitudinal charge-density waves can be observed. The frequency of these waves is a direct result from the permittivity of the sample thus knowing the loss in energy of an electron due to this effect yields information about the sample permittivity.

Single-electron excitation and fine structure
In addition to the previously stated effect a incident shot electron can also excite a single electron into a higher energy state, these can be observed by fine-structure peaks that occur at energies above and below the plasmon peak, resulting in a more jagged profile. Between the 0-10eV range.

Core-electron excitation
Electrons located in the inner shells of a atom have high binding energies ($10^2...10^3 eV$) whose ionisation gives rise to the **ionisation edges** in the ELS. Since these edges are different for every atom they can be used to determine which materials are present in a sample.

Core-Loss fine structure
Depends on the density of states

3. **Applications and Limitations of TEM-EELS**
Thickness measurement
The spectrum can be used to provide a per pixel thickness of the material

Electron properties
The spectrum can provide information of the bandgap of semiconductors and insulator.

Plasmon spectroscopy
The plasmon energy is related to many mechanical properties of the material

Elemental analysis
Because each ionisation edge occurs at an energy loss that is characteristic of a particular element, EELS can identify elements in a material.

Spatial resolution
EELS provides a spatial resolution of about 0.2nm when compensating for aberrations, to go beyond this point room sized specialised set-up are needed

Magnetic measurments
Using a spin-polarised electron source the local magnetic properties of a material can be mapped.

Damage
Shooting electrons at a sample damages it with doses needed for a certain degree of damage differing per material. Resembles the radiation dose calculations from HS.

2012 - Angular momentum resolved EELS by energy filtered nanobeam diffraction

Information in this paper:

Using a Ω-filter, a filter which allows the filtering of electron energies, the team behind the paper was able to select one data cube and its angular resolved vectors. This resulted in data that was more complete than data gotten with the aperture shift method. The new method also preserves parallel illumination of the sample while creating a 3D data cube resolved in diffraction angle. All this comes at a cost of a loss in energy resolution but increases momentum resolution.
This technique overcomes the issue of convolution between EELS spectra and area-selecting apertures.

2015 - Spatially and momentum resolved energy electron loss spectra from an ultra-thin $PrNiO_3$ layer.

Information in this paper:

The paper start of by stating that MREELS (Momentum resolved electron energy-loss spectroscopy) is capable of determining dispersions and thus can image bandgaps, bonding anisotropy, as well as indirect and dipole-forbidden excitations (excitations that are only allowed in higher-order approximations at low rates).
The momentum loss is determined by a scattering process similar to X-ray diffraction. By selecting a certain angle a MREELS set-up is capable of determining energy loss ΔE and momentum transfer $||\vec{q}||$.
The obtainable spatial resolution is determined by the angle of convergence of the electron beam, lens aberrations and the diameter of the selecting aperture.

2017 - Momentum-resolved electron energy loss spectroscopy for mapping the photonic density of states.

Information in this paper:

This paper informs about using momentum resolved electron energy-loss spectroscopy (q-EELS) to probe the momentum resolved photonic density of states (q-PDOS).
When probing a material that has no translational invariance along the electron path there is a distinction between q-EELS and q-PDOS. q-EELS has a loss function produced by an inductive field produced by a moving charge whereas the loss function of q-PDOS is the result of an oscillating electric dipole. This difference presents itself in momentum and position space. In momentum space we see different relations between the energy-loss-function and the transferred electron-momentum into the material.

2019 - Momentum-resolved dielectric response of free-standing mono-, bi-, and trilayer black phosphorus.

Information in this paper:

The team of researches was able to determine the bandgap- and binding- energy as well as the dielectric function for single, double and triple layer black phosphor. They reported on a small deviation which they believed came from screening from there different method of imaging without a substrate. They used a similar filtered set-up as previous papers so they probably used MR-EELS to determine the optical properties, but this is **just a guess**. The effect of quantum confinement for small layer numbers on excitonic properties vanishes when there is strong screening from the environment.
They did use MR-EELS to probe the dielectric response of ultrathin BP with electrons in the $10 - 40eV$ range as well as the dispersion (so also the DOS? applying q-PDOS).