Off-axis electron holography of doped semiconductors

**Off-axis electron holography**

Off-axis electron holography uses a biprism to interfere an electron wave that has passed through a sample with a reference wave that has passed through vacuum. In the absence of magnetic fields and strong diffraction contrast, the phase change, \( \Delta \phi \), of an electron wave passing through a material with electrostatic potential \( V_e \) is given by the expression:

\[
\Delta \phi = C_e V_e t
\]

where \( C_e \) is a constant that depends on the energy of the electron beam and \( t \) is the sample thickness.\(^1\)

**Motivation**

- Electron holography can provide high resolution 2-D maps of the phase shift across a specimen.
- In some circumstances the phase shift is directly proportional to the mean inner potential, therefore the electrostatic potential arising from dopant atoms in the semiconductor device is revealed.
- Electron holography can provide the semiconductor industry with a 2-D and 3-D dopant profiling technique, which can reach sub-10nm resolution.

**Sample preparation using focused ion beam milling.**

FIB (focused ion beam) milling is a site-specific technique ideally suited for thinning samples containing semiconductor devices.
- Samples of uniform thickness can be prepared.
- FIB milling creates amorphous surface layers with significant Ga implementation.
- In addition, sample preparation may also create surfaces with a different, unknown potential distribution.

**Discussion of results**

The built-in potential, \( V_B \), across a p-n junction can be calculated using equation (3), where \( k \) is Boltzmann’s constant, \( T \) the temperature, \( q \) the charge on an electron, \( N_D \) and \( N_A \) the donor and acceptor doping concentration respectively.

\[
V_B = \frac{kT}{q} \ln \left( \frac{N_A}{N_D} \right) \tag{3}
\]

This can be substituted into equation (1) to reveal the expected phase change across a p-n junction.

**Conclusions**

- It has been shown that FIB-prepared GaAs samples have a larger electrically ‘dead’ layer than Si.
- The electrically ‘dead’ layers may be associated with Ga+ implantation in the FIB.
- Further work is required to determine the mechanism of this damage.
- More advanced sample preparation techniques are required in order to characterise the electrical properties of semiconductors using electron holography.

**References**


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