Evaluation of defects in Si-based power devices by cathodoluminescence (CL)

Wide bandgap semiconductors such as silicon carbide (SiC) and gallium nitride (GaN) have been investigated for next-generation power devices. However, silicon (Si) is still the most important semiconductor. Failure analysis and process optimization by CL are presented.

1. Generation processes of defects in Si-based devices and influence on device characteristics

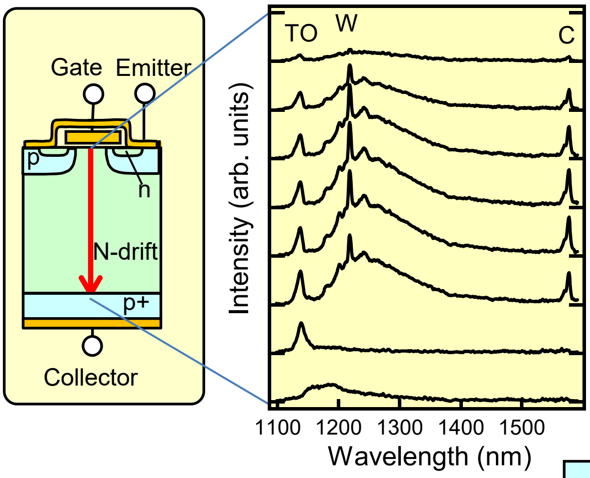
Types of defects	Dimension	Generation process	Influence on device characteristics	Methods
Point defects (interstitials, vacancies, their complexes, etc.)	0D	Ion implantation, dry etching, mechanical process, etc.	Carrier lifetime, carrier concentration, surface leakage, cause of dislocation and stacking fault	Luminescence (PL, CL), ESR, DLTS, RBS channeling, positron annihilation, etc.
Dislocations and stacking faults	1D, 2D	Epitaxial growth, STI, ion implantation, silicide, mechanical process, etc.	Junction leakage, carrier concentration, breakdown voltage degradation	TEM, luminescence (PL, CL), wet etching, X-ray topography, etc.
Precipitations, bulk defects, etc.	3D	Thermal treatment of high oxygen concentration wafer etc.	Junction leakage, breakdown voltage degradation	Wet etching, luminescence (PL, CL), TEM, SIMS, etc.

2. Advantages of CL analysis for Si-based devices

1. Si wafer is nearly perfect crystal. Killer defects are often generated during device-fabrication.
2. Although Si is indirect transition material, many types of defect-related emissions have been reported.
3. SEM can be used for identification of measurement points. Local area in the devices can be easily evaluated.
4. Depth-resolved measurement can be easily achieved by changing acceleration voltage.

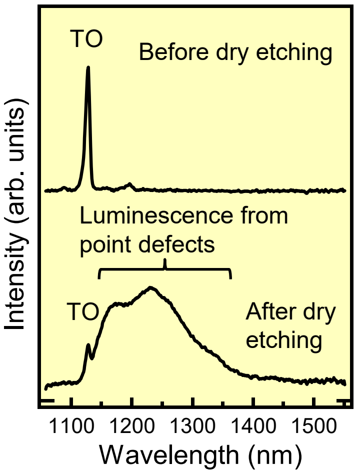
3. Examples

Distribution of point defects in IGBT



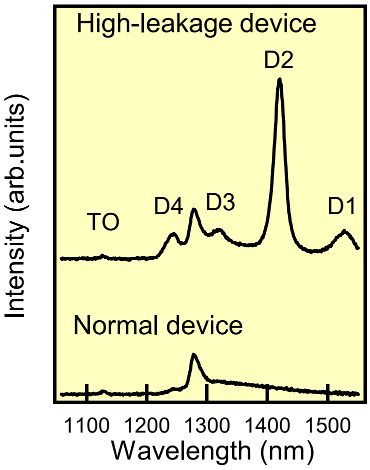
Cross-sectional CL measurement was applied to IGBTs. Sharp lines denoted by W and C are emissions from point defects. These point defects may affect carrier lifetime and carrier concentration in the N-drift layer.

Optimization of dry etching



After dry etching, we observed two distinct features; a broad luminescence emerged and the TO line, which correspond to band-to-band transition, became weak. Process conditions can be optimized by CL measurements.

Analysis of leakage failure in Si device



A high-leakage device showed D1, D2, D3, and D4 lines that come from dislocations in the device. Excess stress during device fabrication can be the root cause of the leakage failure.

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