Semiconductor Optical Communication Components and Devices
Lecture 30: Lasers Reliability

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Laser Reliability: Reasons

The main factors that affect the reliability of a diode laser are:
1. Increase in Threshold current.
2. Decreasing slope efficiency (external differential quantum efficiency).
3. Longitudinal modes.

The mechanisms due to which these can happen are:

**Internal degradation**
1. Active region degradation.
2. Lateral confinement degradation.
3. Ohmic contact degradation.

**External degradation**
1. Mirror Facet degradation.
2. Thermal contact solder degradation.
3. Fiber coupling degradation.
Laser Reliability: Active region degradation:

Due to operation of the lasers at high current densities there are carriers with high energies and high thermal gradients exist in the active region, resulting in:

Precipitation of host atoms, growth of dislocations, defect migration, intermixing in quantum well lasers, etc.

The effects can either have shorts across the P-N junction or lead to higher non-radiative recombination by dark line defects. Both would go to increase the threshold current and reduce the slope efficiency.

Lateral confinement degradation

During laser operation, defects may be created in the current confining layers resulting in a resistive shunt path leading to leakage current, thus effecting threshold current and efficiency. Quantum well intermixing used for defining the lateral confinement is found to be resistant to lateral confinement degradation.
**Laser Reliability: Ohmic contact degradation:**

Usually two types of Ohmic contacts are used, namely (a) Schottky type with very narrow barriers (b) Alloyed contacts. The former is mostly used in compound semiconductors with high doping. Minimization of the series resistance and reliability are of main concerns. Gold forms Au$_2$In and Au$_2$P$_3$ highly resistive clusters at the contact interface with InP. These clusters may grow with time and ruin the operation of the laser diode.

Out diffusion of Group-III elements under High current operating conditions gives rise to high resistivity in the depletion region of Schottky type contacts. The contact-metal/Gr.-V alloy offers a high resistance leading to metal/Gr.-III low resistance spikes that reach the active region forming large filamentary currents across the PN junction that may ruin the laser.

Although Au is a good contact material for bonding its diffusion into the active region is very undesirable due the formation of recombination centres.
Laser Reliability: Facet Degradation

The facets handle high power densities (MW/cm²) and are therefore degraded due to optical absorption at the facet.

A slow mode of degradation is due to photo-assisted oxidation of the surface, specially for Al-containing compounds which increases the Auger recombination loss. The thickness of the oxide layer is dependent on the square root of the operating time. The output energy, power density, moisture, and composition of the active layer.

A more sudden collapse is due to catastrophic damage of the facet arising out of either defects where absorption occurs or defects at which foreign absorbing materials gets adsorbed leading to sometimes a meltdown of the facet. A way of reducing this kind of failure is to first, reduce the power density at the facet by tapering the waveguide near the facet (maybe by quantum well intermixing), and second introduce a protective coat for the facet.
Degradation of Solder with heat sink occurs due to the defects, such as air bubbles and foreign material, introduced during the soldering process. One has to do this soldering process at the minimum possible temperature and pressure, which may incur defects unless the process has been optimized. Excessive temperature and pressure during this process may assist in diffusion of the contact Au metal into the active region, thus degrading it, as Au form non-radiative recombination centers in the active region. This is specially true for upside down devices, where the junction is very close to the heat sink.

Fiber coupling degradation occurs mostly due to vibrational deformation of the coupling between the fiber and the active region. It could also occur due to degradation of the index coupling material between the active region and the glass fiber.
Laser Reliability: Elimination of degradation

Slow degradation removal:
1. Avoid residual impurities during epitaxial growth and introduction of traps and deep level defects during growth.
2. Suppress facet oxidation by cleaving laser chips in an inert atmosphere before depositing suitable passivation layers.
3. Eliminate (or manage) internal (strained layer) or external (during wire bonding) stress around the active region.
4. Avoid Au-alloyed type ohmic contacts and employ narrow barrier schottky type contacts.

Sudden-degradation removal:
1. Remove positive feedback loop arising out of surface recombination currents and band shrinkage leading to catastrophic damage of the facet. The techniques used are:
   (a) Active region materials having low temperature dependence of band gap
   (b) Choose active region material with large density of states i.e. QW
   (c) Facet treatment and coating.
   (d) Control of Optical Power and Current Injection.
   (e) Thermal conductivities of the different layers forming the laser structure
Laser Reliability: Elimination of degradation

Life of a Laser Diode

\[ \text{Life of a Laser Diode} = C_t \cdot \exp\left(\frac{E_a}{k_B T_j}\right) \]

Where \( C_t \) is a constant, \( E_a \) is the Activation Energy, \( k_B \) is the Boltzmann constant, and \( T_j \) is the junction temperature in °K.

Depending on the type of laser, typical activation energies range from 0.2 eV to 0.7 eV.

Theoretically, the failure rate is also a function of the current, and power as indicated below, where \( I \) is current and \( P \) is power, \( m \) is the acceleration parameter of current, \( n \) is the acceleration parameter of power.

\[
[\text{Failure Rate}] \propto \left[ \text{Failure Rate} \right]_0 I^m P^n \exp\left( -\frac{E_a}{k_B T_j} \right)
\]

\( E_a = 0.2 \text{ eV} \)
\( E_a = 0.4 \text{ eV} \)
\( E_a = 0.7 \text{ eV} \)
1. A diode laser had been working fine for 200 hrs. at the rated power, but suddenly failed to produce any power except that expected from an LED. Can you suggest a reason for the failure? What would be the possible solutions to avoid this kind of failure?

2. A similar diode as above, which has been working for 5000 hrs. is found to produce less output power at the same bias current over a period of a month. Suggest a reason for this kind of failure. Can this failed laser be restored?

3. What precautions can be taken to avoid soldering and fiber-couple degradation?

4. If the optical output power of a diode laser is linearly dependent on the drive current, then why does the failure rate be dependent exclusively on the m\textsuperscript{th} power of current and n\textsuperscript{th} power of the output optical power?.