Theoretical study of the emission of light in indirect bandgap semiconductor stimulated by phonons

José María Escalante, Alejandro Martinez
Nanophotonics Technology Center, Universitat Politècnica de València, Camino de Vera s/n, 46022, Valencia, Spain

Introduction

Silicon laser: “holy grail” of optical communications

The main roadblock is the fact that the silicon has an indirect energy bandgap and, therefore, it is highly inefficient as a light source.

A phonon of the right energy and momentum is required to produce the transition from the conduction band (CB) to the valence band (CV).

Einstein’s coefficients for indirect gap semiconductors

\[ R_{q} = \text{Stimulated emission of photons and phonons} \]

\[ R_{ab} = \text{Stimulated emission of photons and spontaneous emission of phonones} \]

\[ R_{s} = \text{Spontaneous emission of photons and stimulated emission of phonons} \]

\[ R_{sp} = \text{Spontaneous emission of photons and spontaneous emission of phonons} \]

At thermodynamic equilibrium must be fulfilled

\[ 1 + \frac{B_{s}}{B_{sp}} = 1 \implies B_{s} = 0 \]

\[ B_{sp} = B_{sp} \]

\[ B_{sp}(n_{p} + 1) + B_{sp} = D_{sp}B_{sp}(n_{p} + 1) \implies B_{sp} = 0 \]

Our work

Einstein’s work

\[ B_{sp} = B_{sp} \]

\[ B_{sp} = D_{sp}B_{sp} \]

\[ A_{sp} = D_{sp}B_{sp} \]

Optical gain and the Purcell Effect

The rate of spontaneous emission depends partly on the environment of a light source (excited atom). This means that by placing the light source in a special environment, the rate of spontaneous emission can be modified.

\[ B_{sp} = F_{sp}B_{sp} \]

\[ K_{sp} = F_{sp}K_{sp} \]

\[ \tau_{sp} = F_{sp}\tau_{sp} \]

\[ \tau_{sp} = \frac{F_{sp}}{\tau_{sp}} \]

Below threshold

Above threshold

Carrier density

\[ N = \frac{F_{sp}B_{sp}}{F_{g}} \]

Photon density

\[ N_{0} = N \]

\[ N_{0} = \frac{K_{sp}}{\tau_{sp}} \]

Reference


This work is supported by the European Commission Seventh Framework Programme (FP7) under the FET-Open project TALPHOX No. 233833