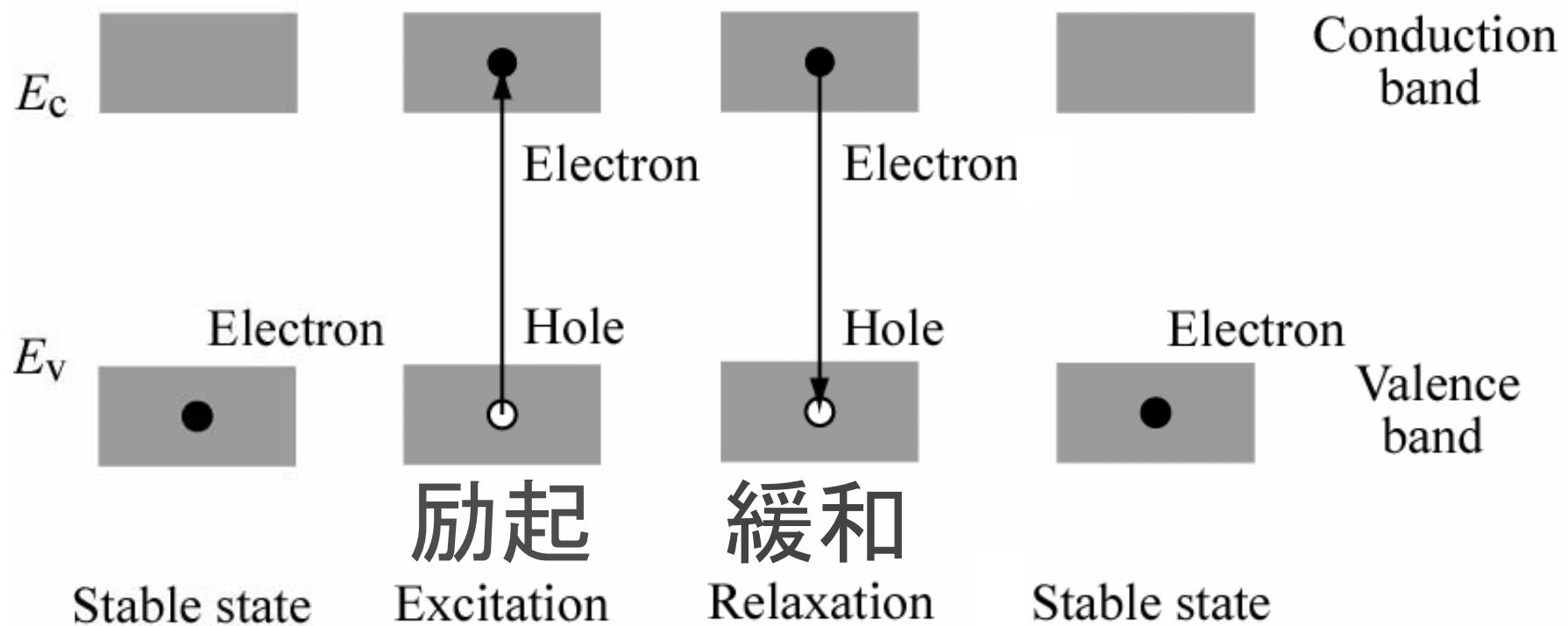


光学遷移

■ 励起と緩和



光学遷移

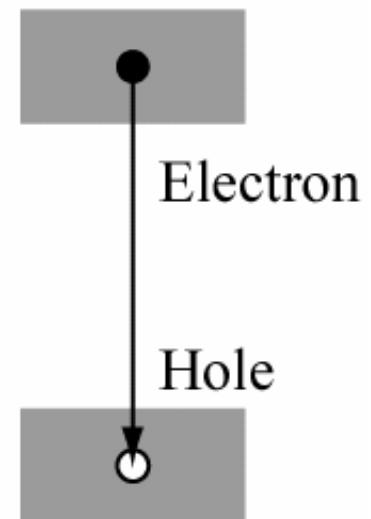
■ 緩和

- 電子と正孔の再結合

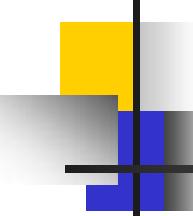
- 発光再結合

- LED, レーザー

- 非発光再結合



緩和
Relaxation



光学遷移

■ 保存則

■ エネルギー保存則

$$E_2 - E_1 = \hbar\omega$$

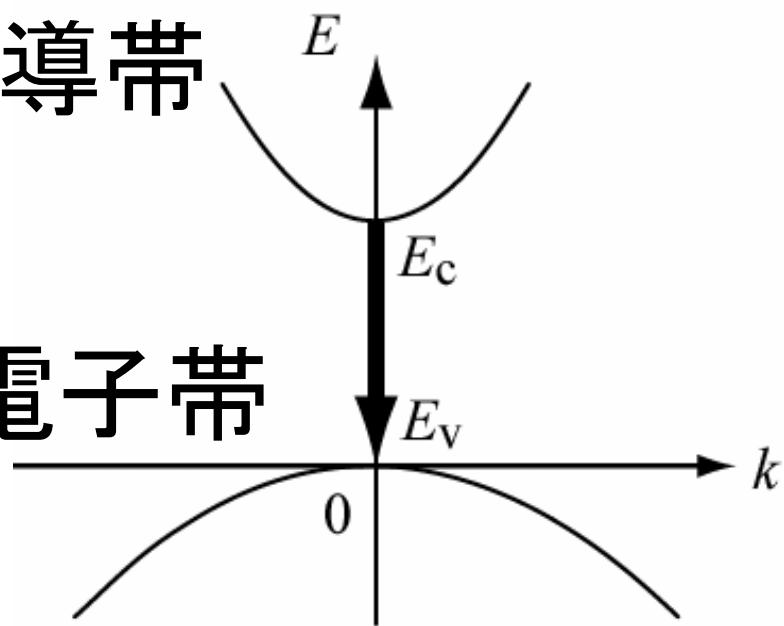
■ 運動量保存則

$$\sum_i P_i = \text{constant}, \quad P_i = \hbar k_i = \frac{h}{\lambda_i}$$

光学遷移

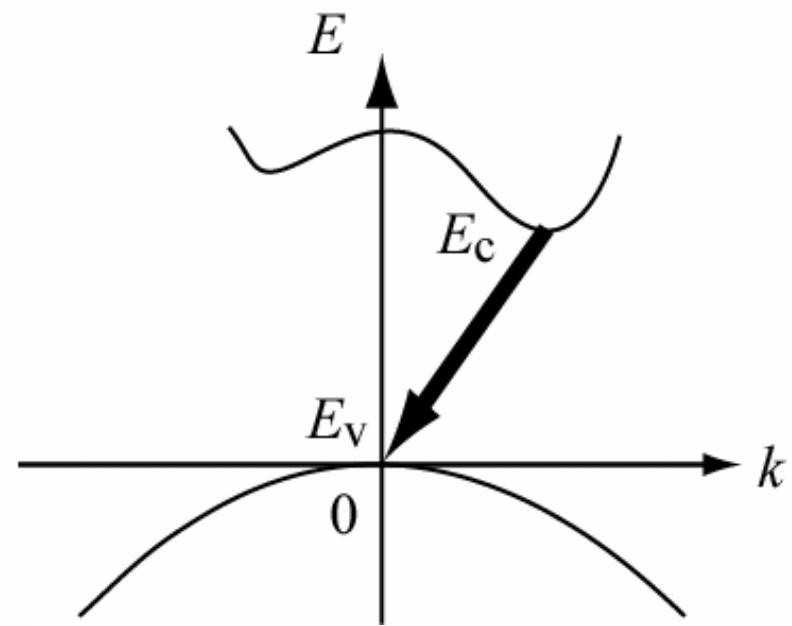
■直接遷移と間接遷移

伝導帯

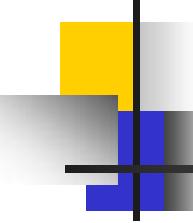


価電子帯

直接遷移



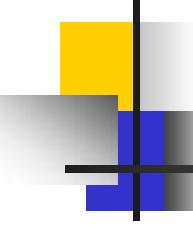
間接遷移



光学遷移

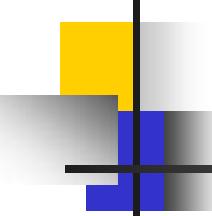
■ 遷移確率

- 直接遷移 遷移確率大
 - 二体(電子, 正孔)衝突
- 間接遷移
 - 三体(電子, 正孔, フォノン)衝突



発光過程の分類

- 寿命
 - 蛍光
 - 短い: 1 ns — 1 ms
 - 燐光
 - 長い: 1 ms — 1 day



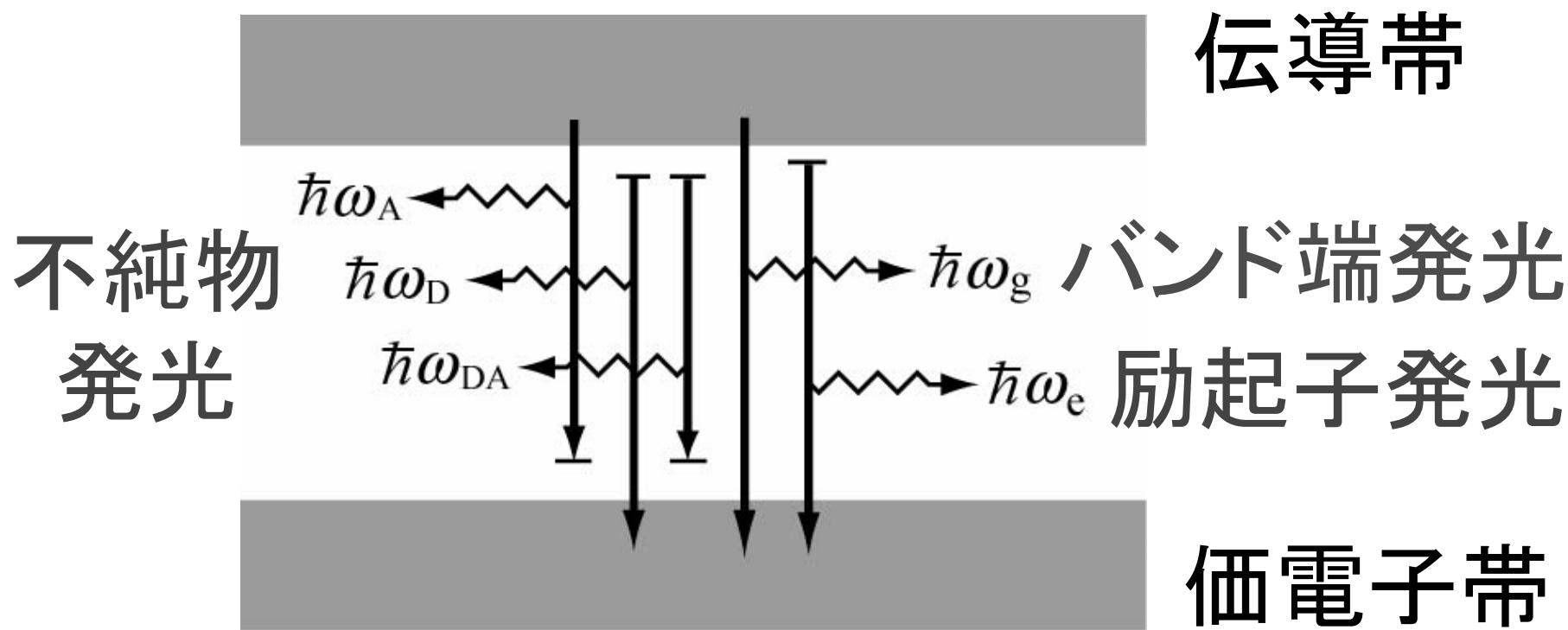
発光過程の分類

■ 励起方法

- 光照射: フォトルミネッセンス
- 電界印加: エレクトロー
- 電流注入: 注入形エレクトロー
- 電子線照射: カソードー

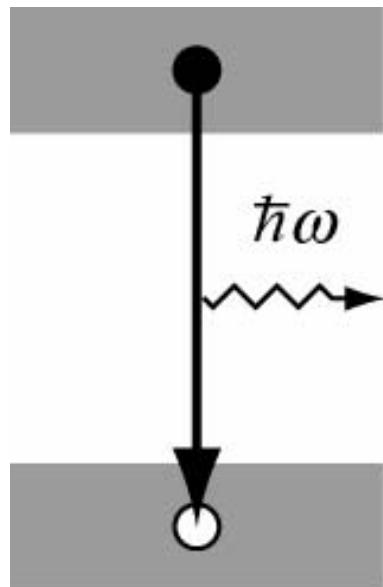
発光過程の分類

■遷移に寄与する状態

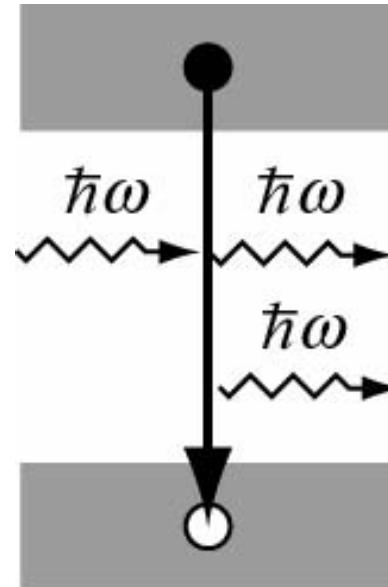


放射と吸收

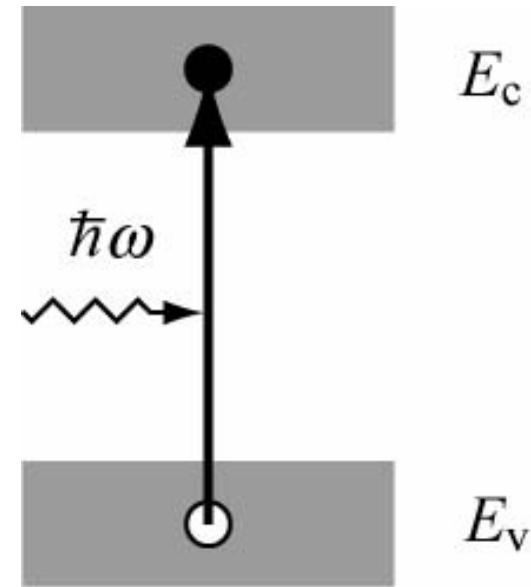
■ 自然放出, 誘導放出, 吸收



自然放出



誘導放出



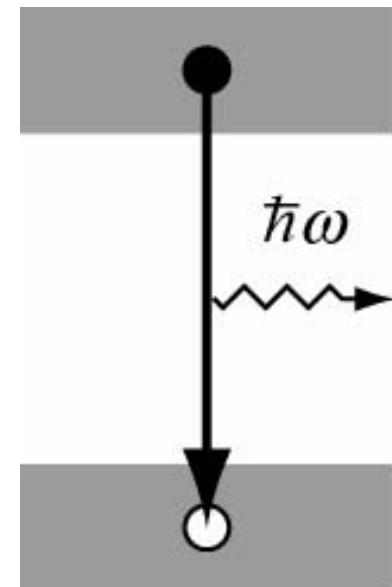
吸 収

E_c

E_v

放射と吸収

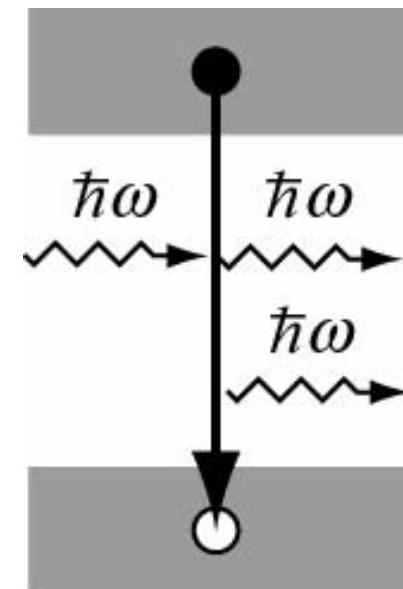
- 自然放出
 - 入射光の有無に無関係
 - 真空場の揺らぎによる誘導放出



放射と吸収

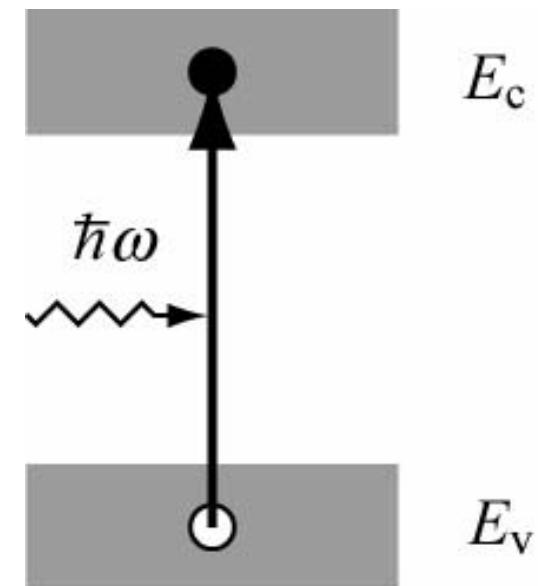
■ 誘導放出

- 入射光と放出光
 - 同波長
 - 同位相
 - 同方向



放射と吸収

- 吸収
 - 誘導吸収のみ
 - 自然吸収なし

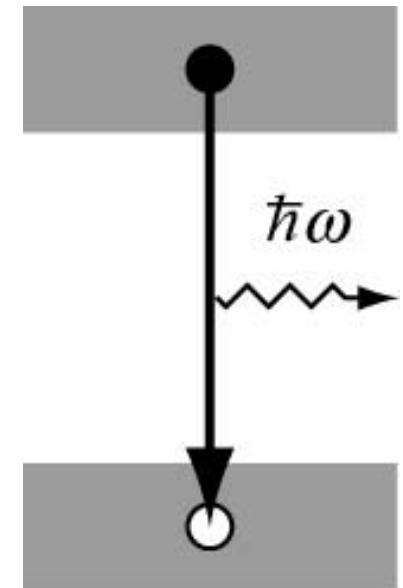


放射と吸収

■ 発光ダイオード : LED

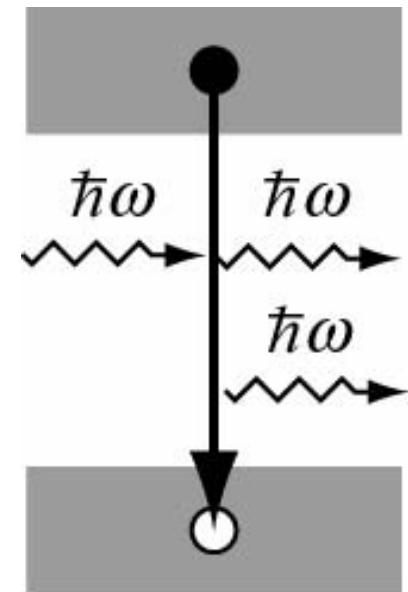
■ Light Emitting Diode

■ 自然放出による発光



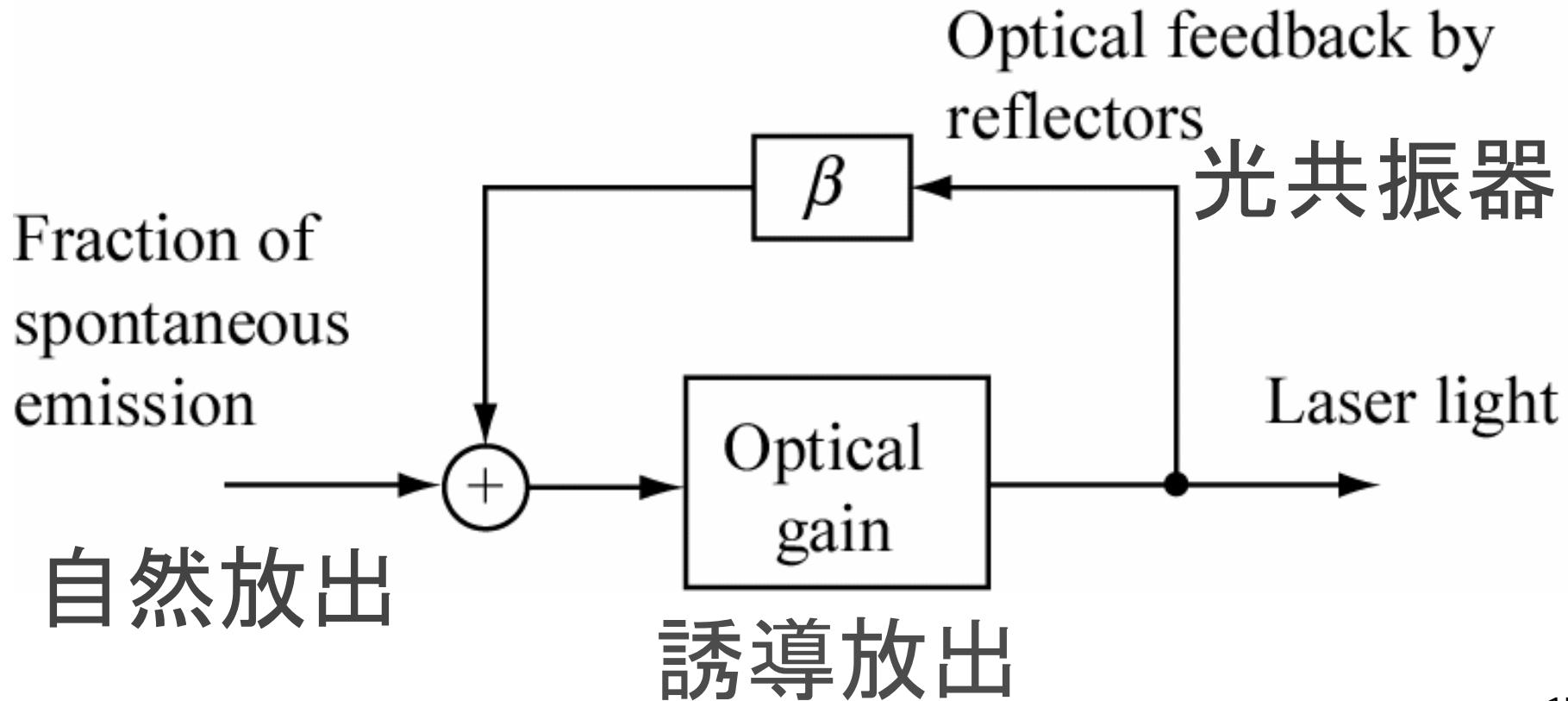
放射と吸収

- レーザー : LASER
- Light Amplification by Stimulated Emission of Radiation
- 放射の誘導放出による光増幅



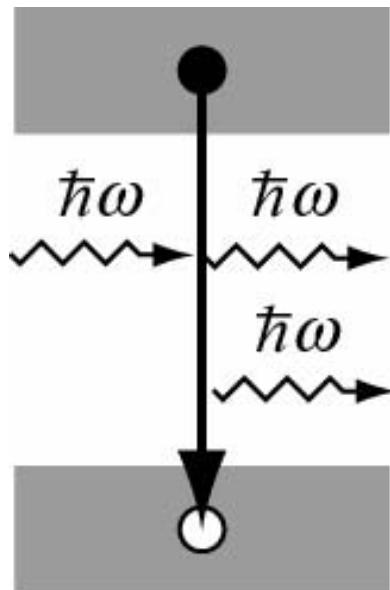
放射と吸収

レーザー発振器

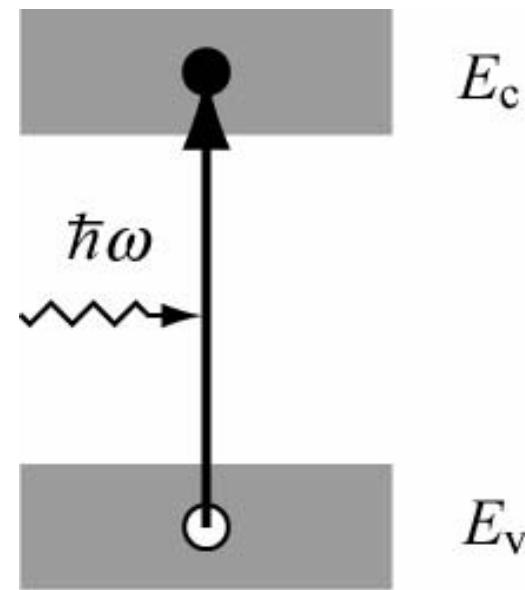


放射と吸収

■ 誘導放出による光増幅



誘導放出



吸 収

E_c

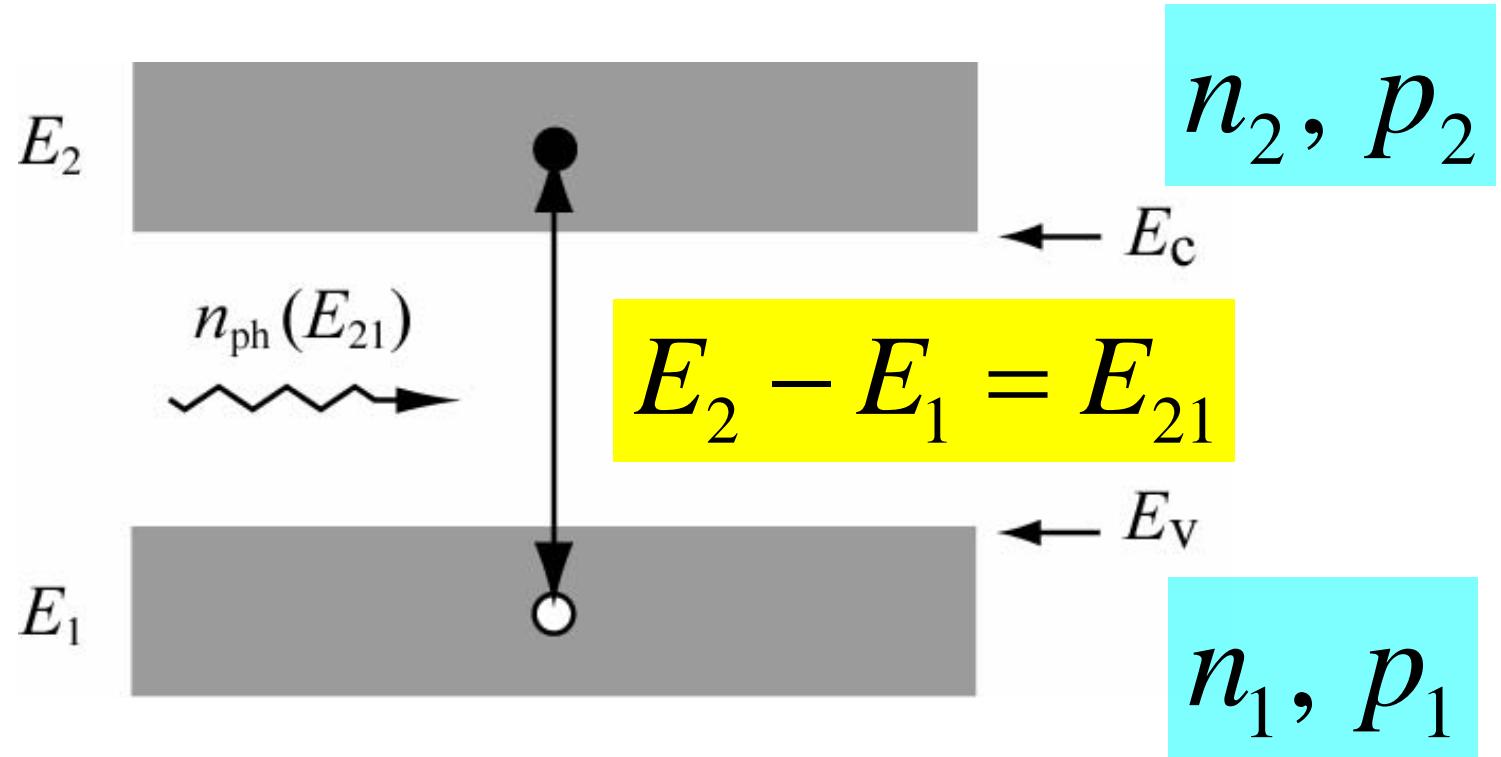
E_v

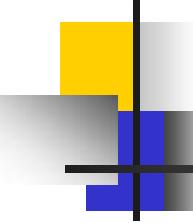
$$n_c > n_v$$

反転分布

光利得

■光学遷移レート





光利得

■ 誘導放出率

$$r_{21}(\text{stim}) = B_{21} n_2 p_1 n_{\text{ph}}(E_{21})$$

■ 吸収率

$$r_{12}(\text{abs}) = B_{12} p_2 n_1 n_{\text{ph}}(E_{21})$$

■ 自然放出率

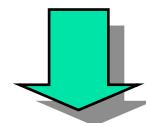
$$r_{21}(\text{spon}) = A_{21} n_2 p_1$$

光利得

■ 热平衡状态

$$r_{21}(\text{stim}) + r_{21}(\text{spon}) = r_{12}(\text{abs})$$

$$E_{F1} = E_{F2} = E_F$$



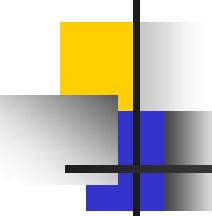
$$n_{\text{ph}}(E_{21}) = \frac{A_{21}}{B_{12} \exp[E_{21}/(k_B T)] - B_{21}}$$

光利得

- EinsteinのA係数, B係数
- 黒体放射との比較

$$n_{\text{ph}}(E_{21}) = \frac{8\pi n_r^3 E_{21}^3}{h^3 c^3 \exp[E_{21}/(k_B T)] - h^3 c^3}$$

$$B_{21} = B_{12} = B, \quad A = \frac{8\pi n_r^3 E_{21}^3}{h^3 c^3} B$$



光利得

■ 正味の誘導放出率

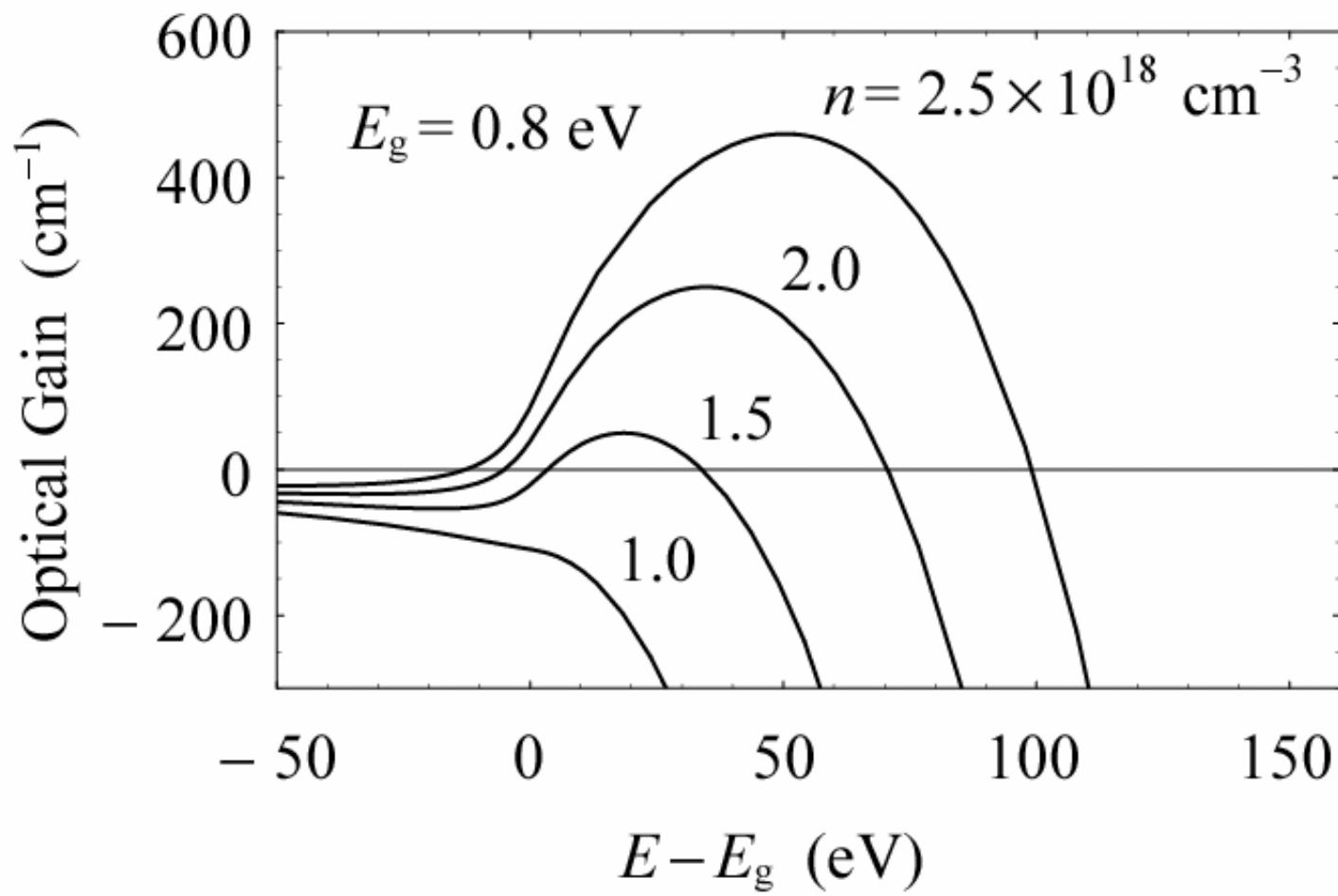
$$r^0(\text{stim}) = r_{21}(\text{stim}) - r_{12}(\text{abs})$$

■ 反転分布条件

$$f_2 > f_1$$

$$E_{\text{Fc}} - E_{\text{Fv}} > E_{21}$$

光利得スペクトル



発光スペクトル

