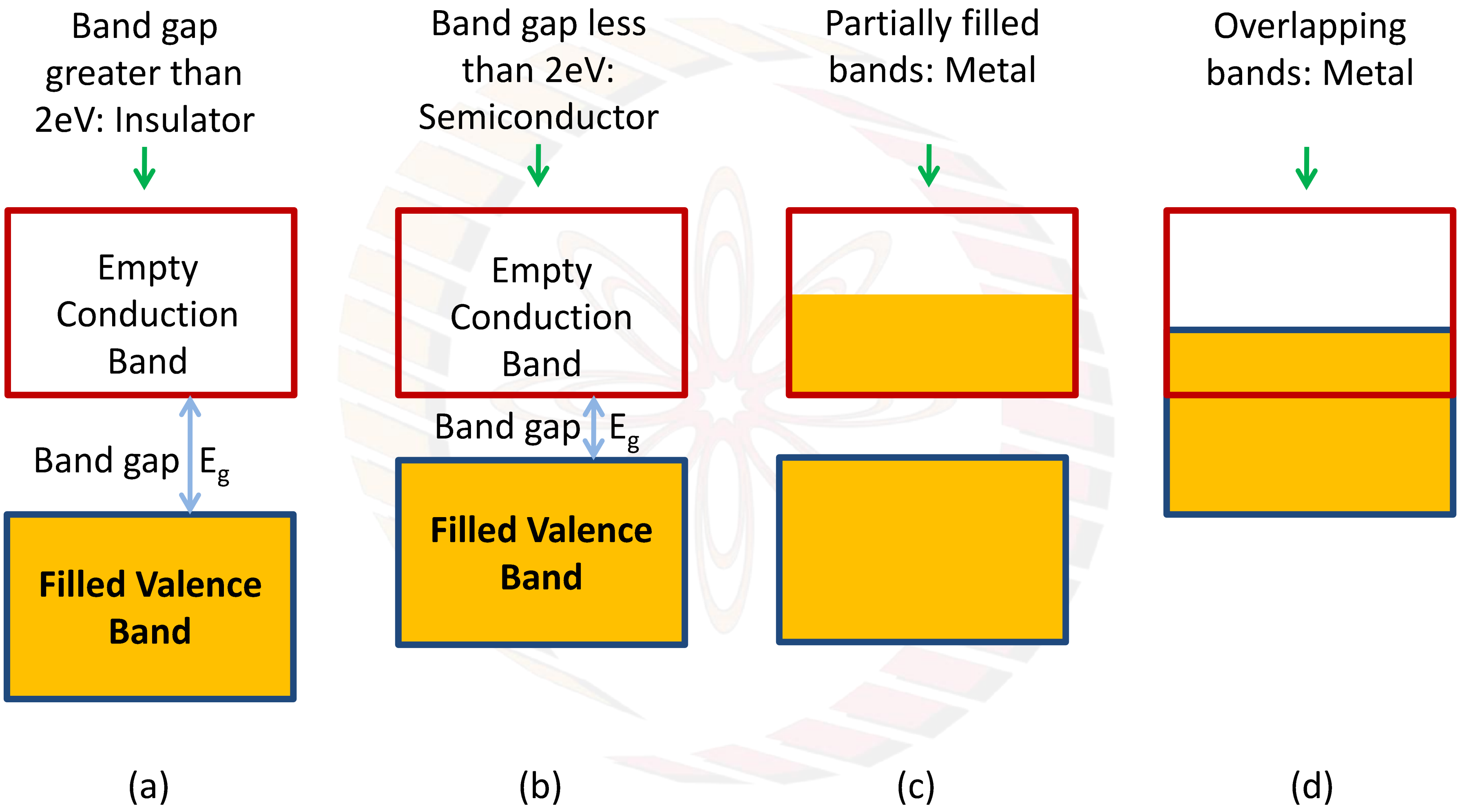
Solar Energy:
The Semiconductor

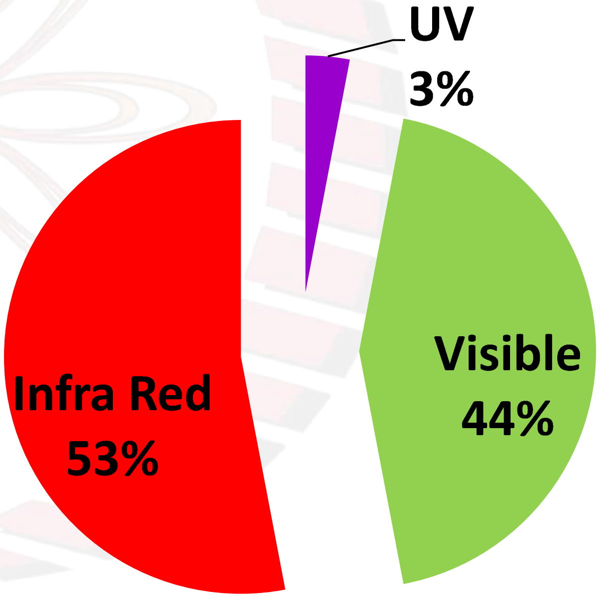
Learning objectives:

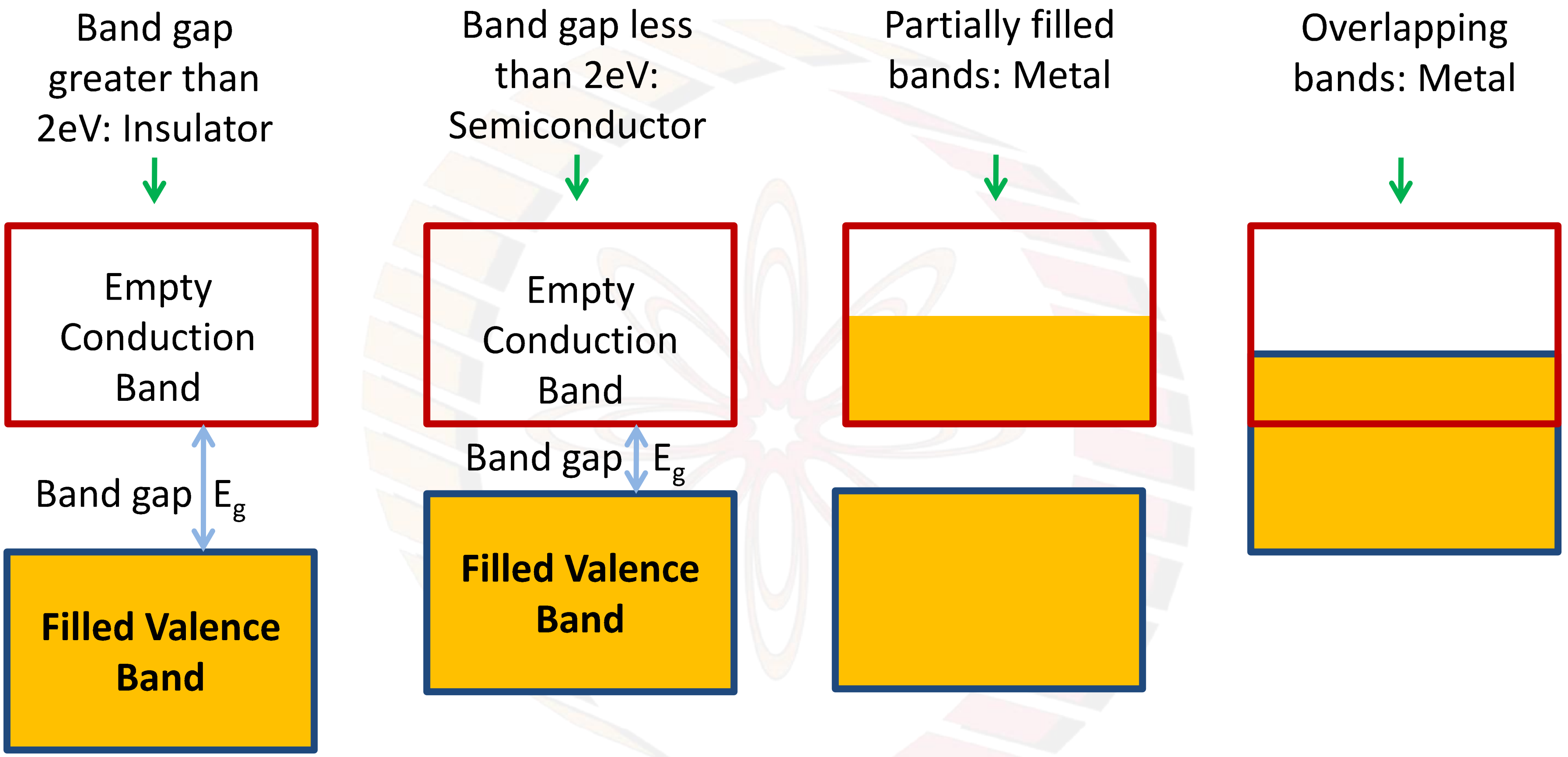
1) To plot the band diagrams of materials
2) To explain the interaction of bands with radiation
3) To understand the different ways in which band diagrams can be plotted.



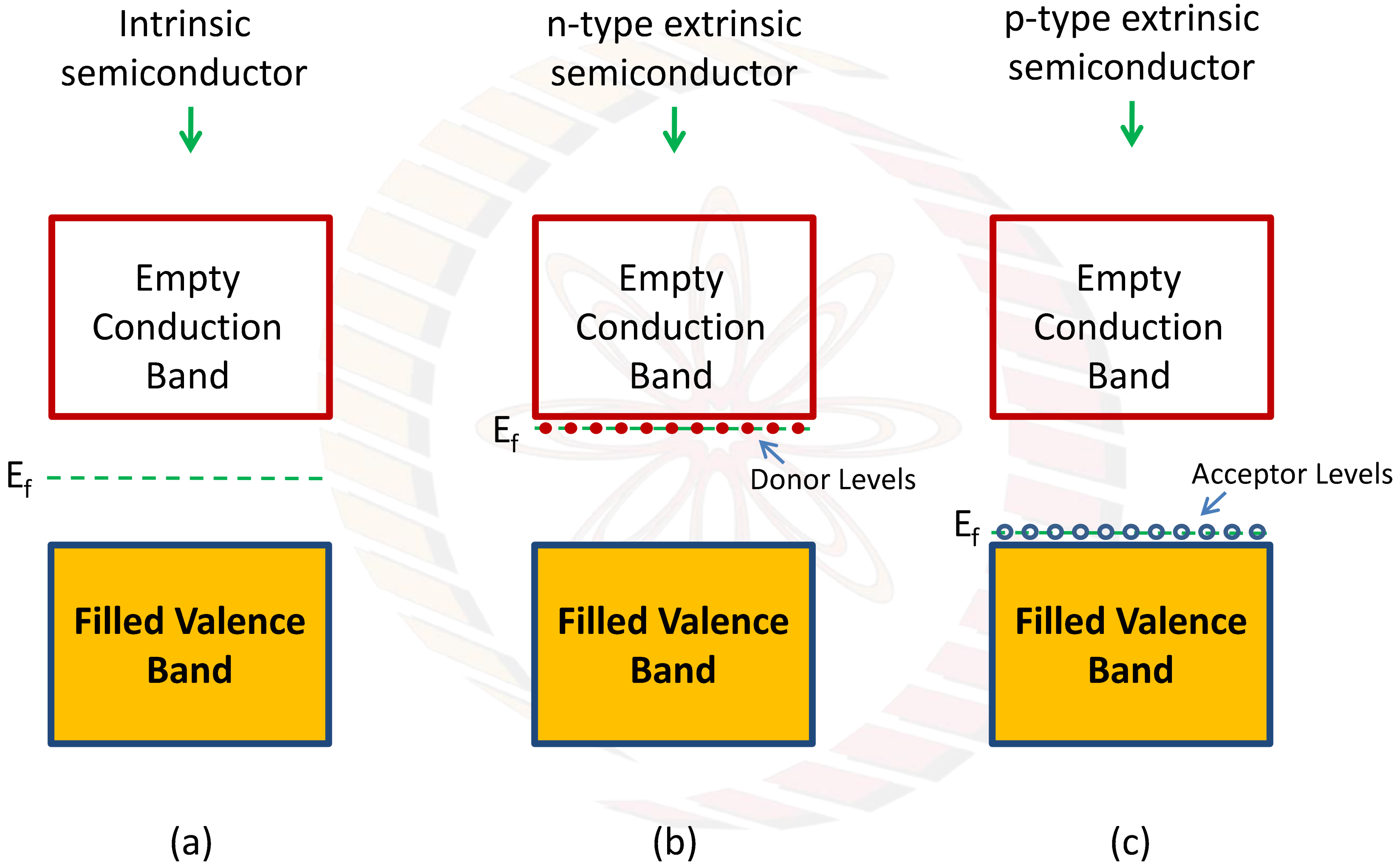
Band gap greater than 2eV: Insulator
Empty Conduction Band
Band gap E_g
Filled Valence Band
(a)
Band gap less than 2eV: Semiconductor
Empty Conduction Band
Band gap E_g
Filled Valence Band
(b)
Partially filled bands: Metal
(c)
Overlapping bands: Metal
(d)

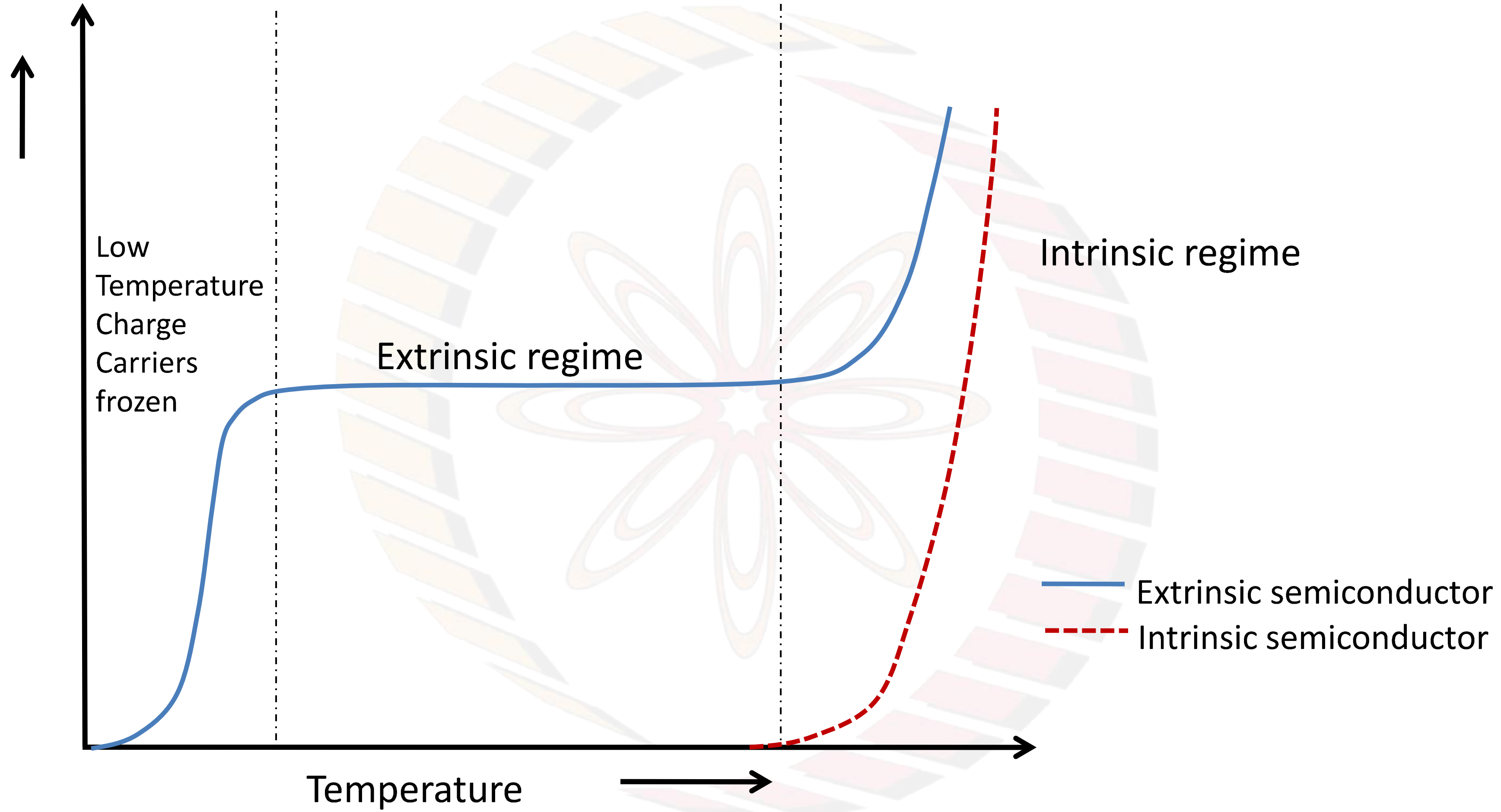
Visible Spectrum Wavelength:	400 nm (violet)	to	700 nm (red)
Corresponding band gaps:	3.1 eV	to	1.8 eV





Visible Spectrum Wavelength:	**400 nm (violet)**	**to**	**700 nm (red)**
Corresponding band gaps:	**3.1 eV**	**to**	**1.8 eV**


Intrinsic semiconductor
n-type extrinsic semiconductor
p-type extrinsic semiconductor
Empty Conduction Band
Empty Conduction Band
Empty Conduction Band
E_f
E_f
Donor Levels
Acceptor Levels
E_f
Filled Valence Band
Filled Valence Band
Filled Valence Band
(a)
(b)
(c)


Low
Temperature
Charge
Carriers
frozen
Extrinsic regime
Intrinsic regime
Extrinsic semiconductor
Intrinsic semiconductor
Temperature

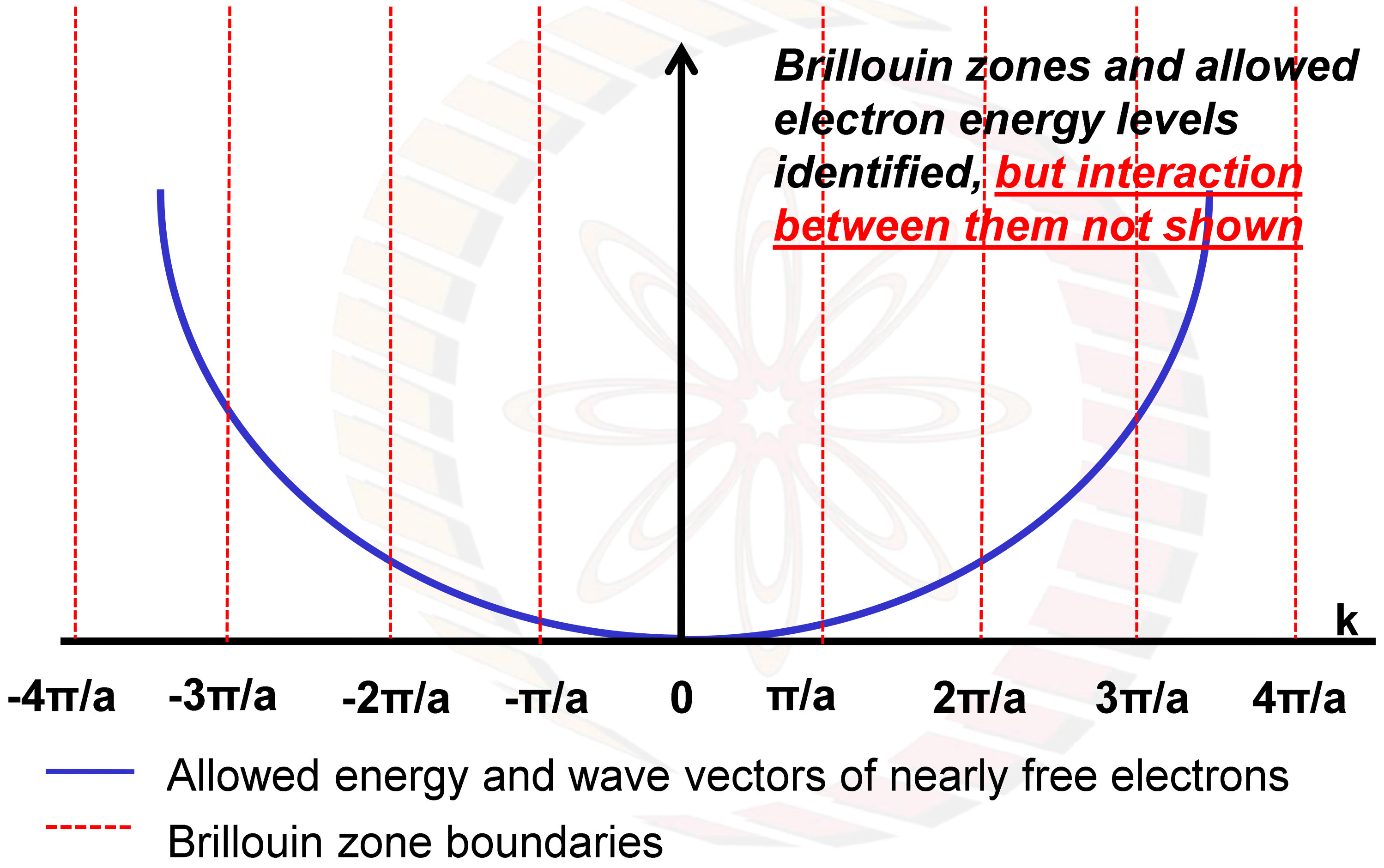
$$E = h\nu$$

Planck

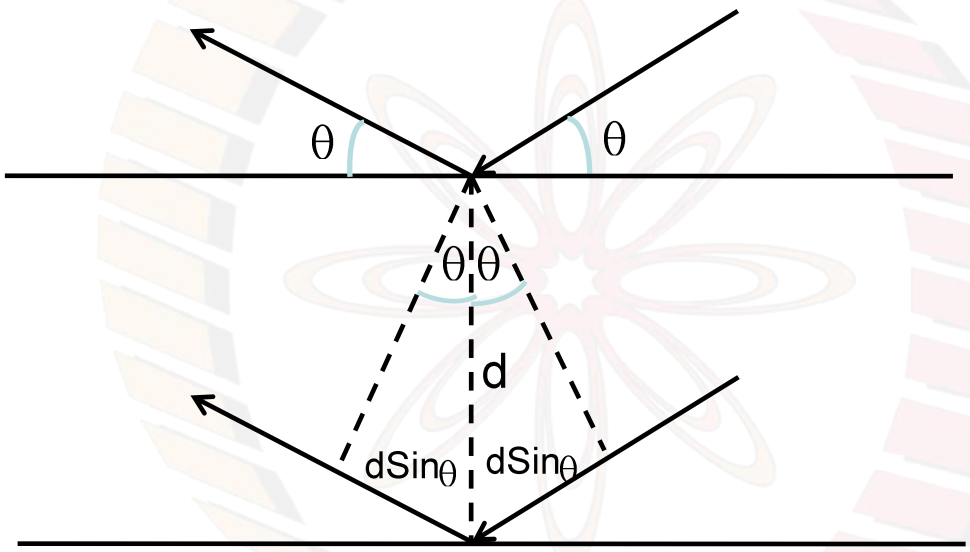
$$\lambda = \frac{h}{p}$$

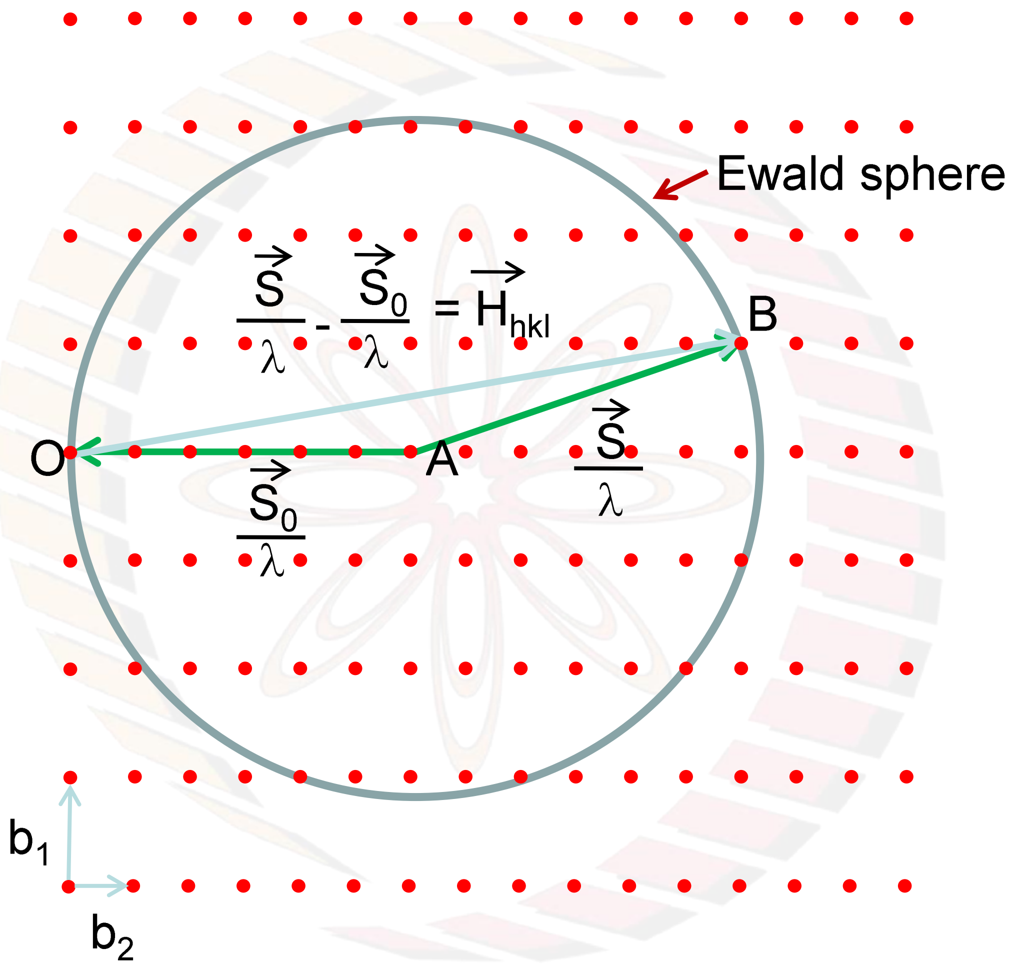
de Broglie

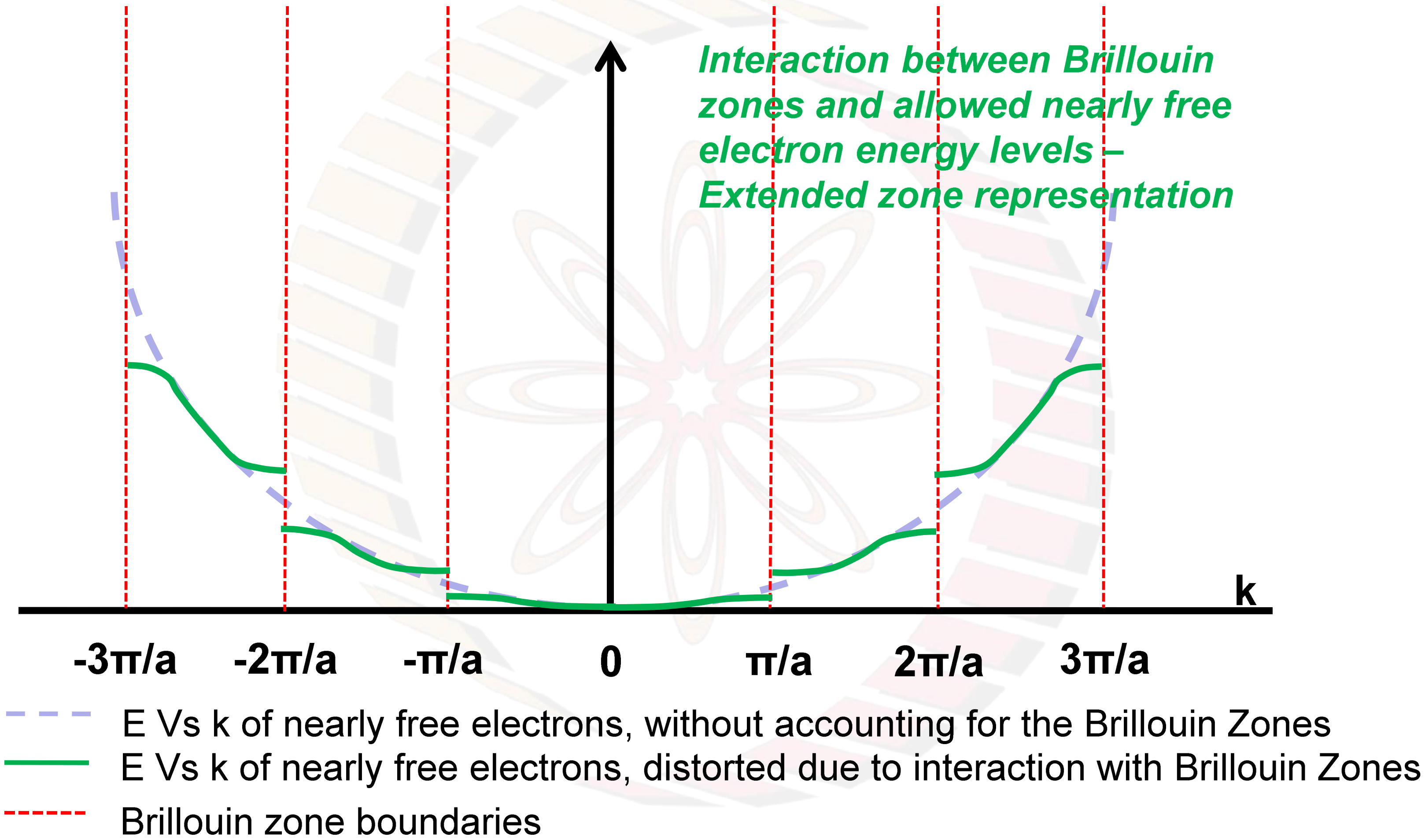
$$E = \frac{\hbar^2 k^2}{2m}$$



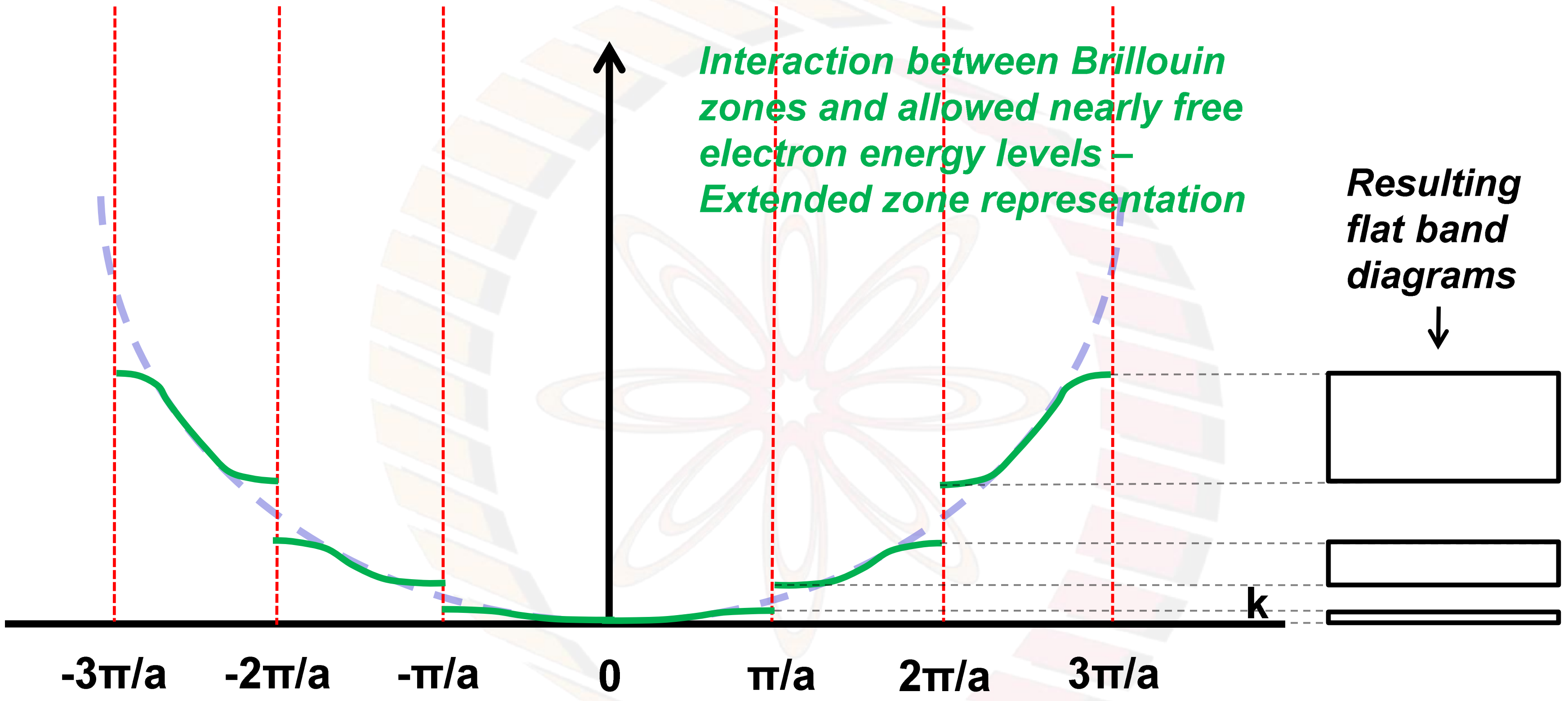
Brillouin zones and allowed electron energy levels identified, but interaction between them not shown
k
-4π/a
-3π/a
-2π/a
-π/a
0
π/a
2π/a
3π/a
4π/a
Allowed energy and wave vectors of nearly free electrons
Brillouin zone boundaries


θ
θ
θ θ
d
dSinθ
dSinθ

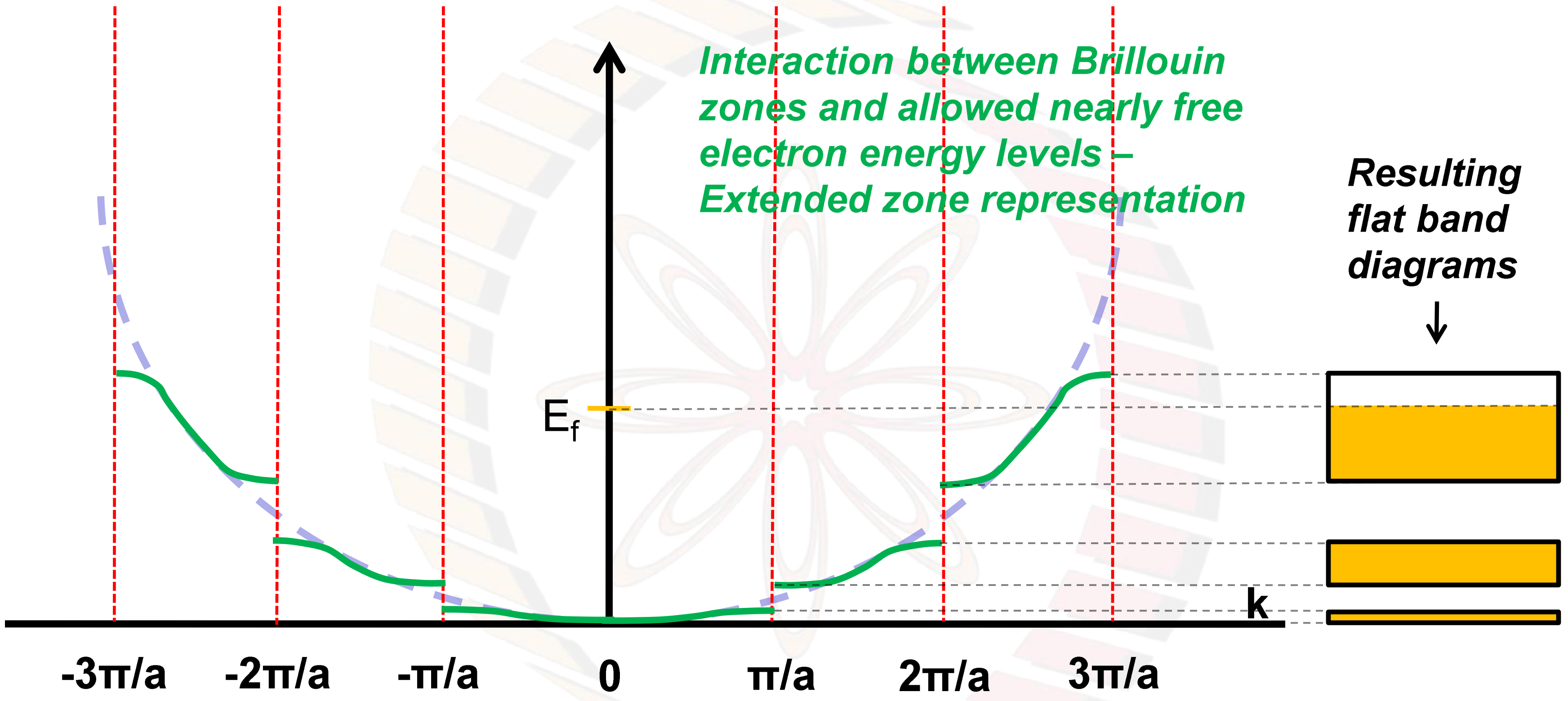

Ewald sphere
$\frac{\vec{S}}{\lambda} - \frac{\vec{S_0}}{\lambda} = \vec{H}_{hkl}$
B
O
A
$\frac{\vec{S}}{\lambda}$
$\frac{\vec{S_0}}{\lambda}$
b_1
b_2



Interaction between Brillouin zones and allowed nearly free electron energy levels – Extended zone representation
k
-3π/a
-2π/a
-π/a
0
π/a
2π/a
3π/a
E Vs k of nearly free electrons, without accounting for the Brillouin Zones
E Vs k of nearly free electrons, distorted due to interaction with Brillouin Zones
Brillouin zone boundaries



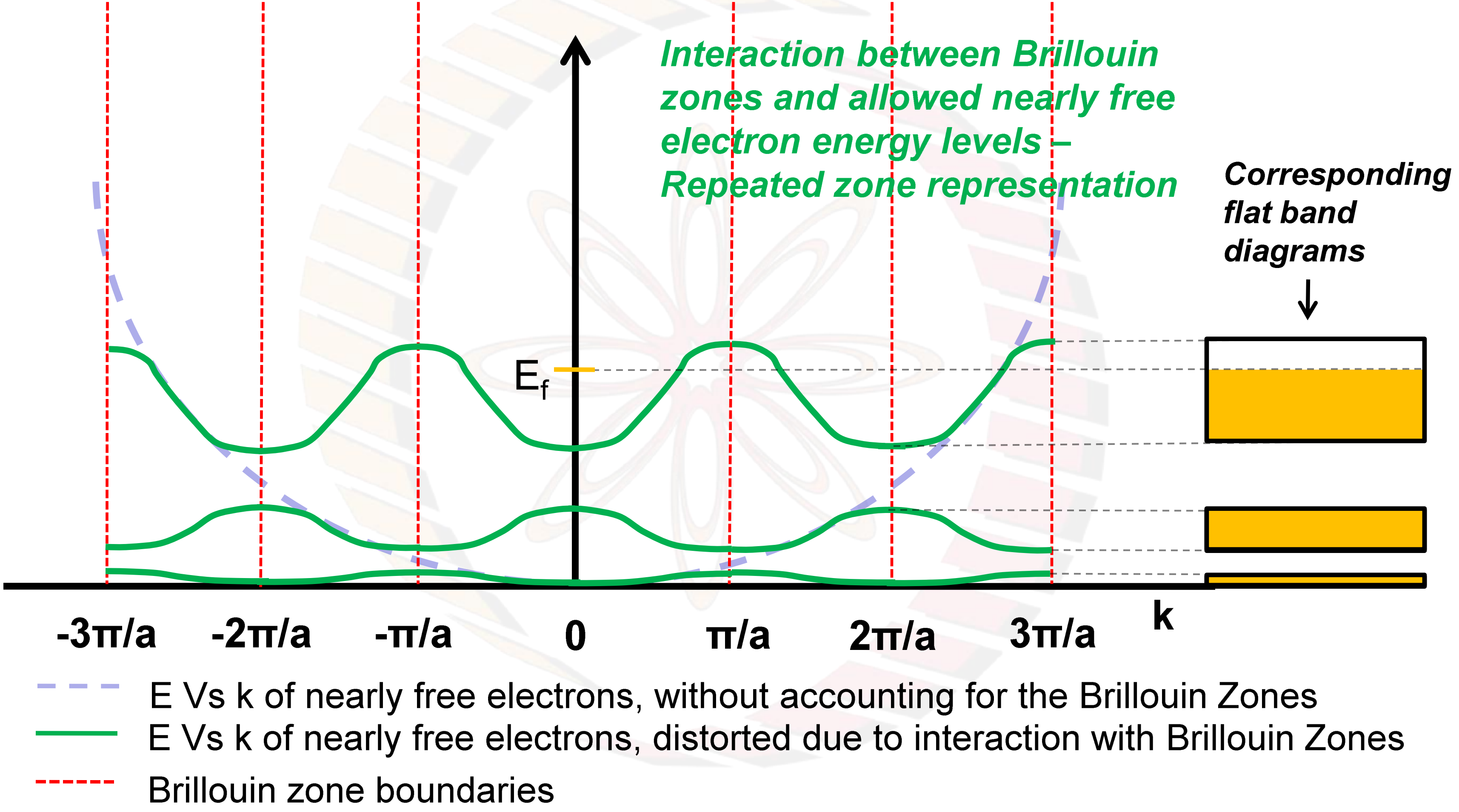
E Vs k of nearly free electrons, without accounting for the Brillouin Zones
E Vs k of nearly free electrons, distorted due to interaction with Brillouin Zones
Brillouin zone boundaries



E Vs k of nearly free electrons, without accounting for the Brillouin Zones

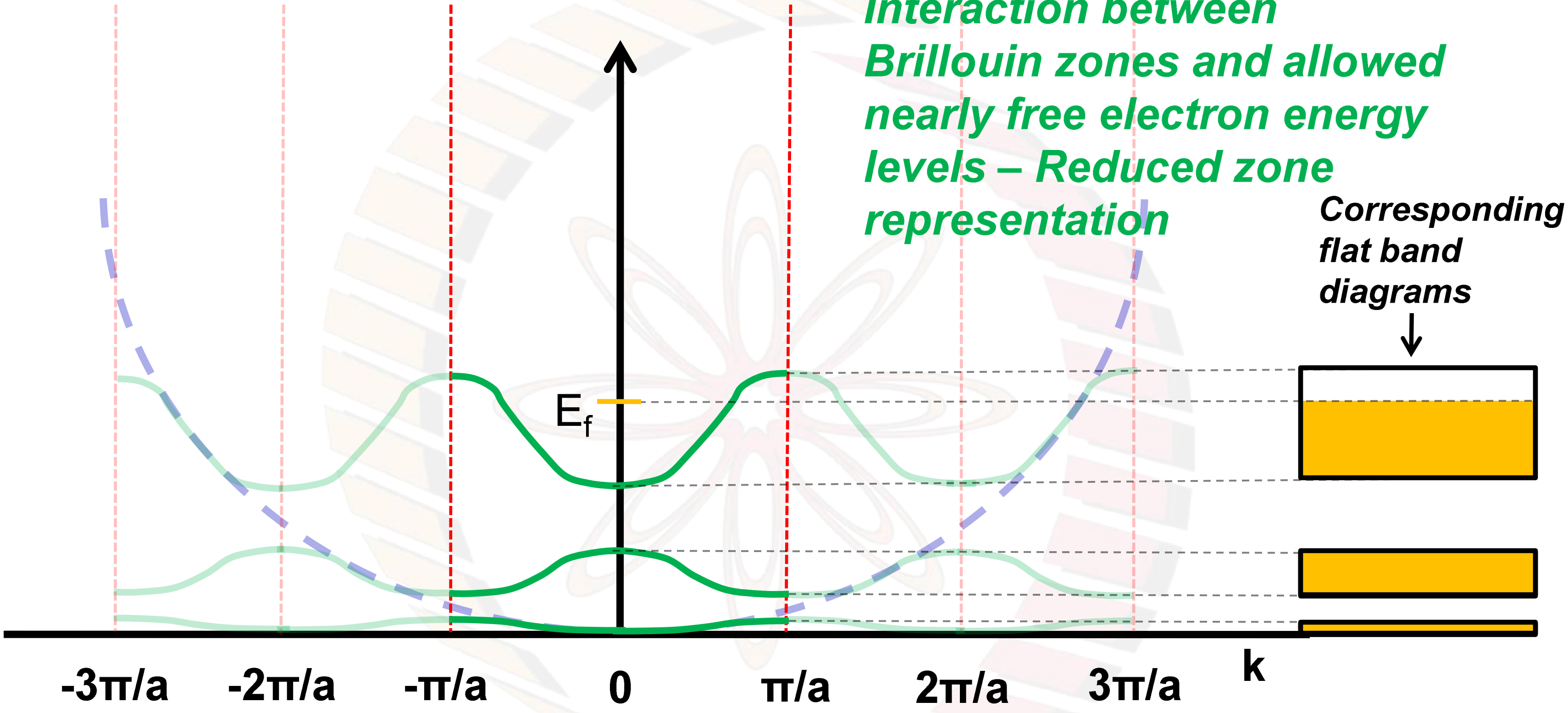
E Vs k of nearly free electrons, distorted due to interaction with Brillouin Zones

Brillouin zone boundaries



Interaction between Brillouin zones and allowed nearly free electron energy levels – Repeated zone representation
Corresponding flat band diagrams
E_f
$-3\pi/a$
$-2\pi/a$
$-\pi/a$
0
π/a
$2\pi/a$
$3\pi/a$
k
E Vs k of nearly free electrons, without accounting for the Brillouin Zones
E Vs k of nearly free electrons, distorted due to interaction with Brillouin Zones
Brillouin zone boundaries

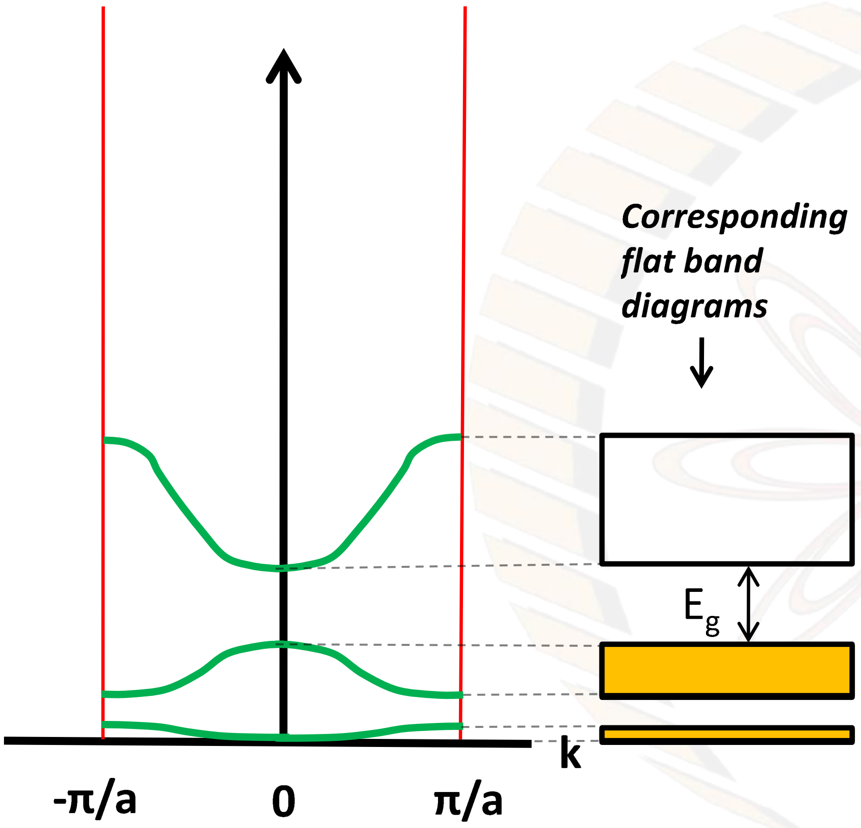
Interaction between Brillouin zones and allowed nearly free electron energy levels – Reduced zone representation



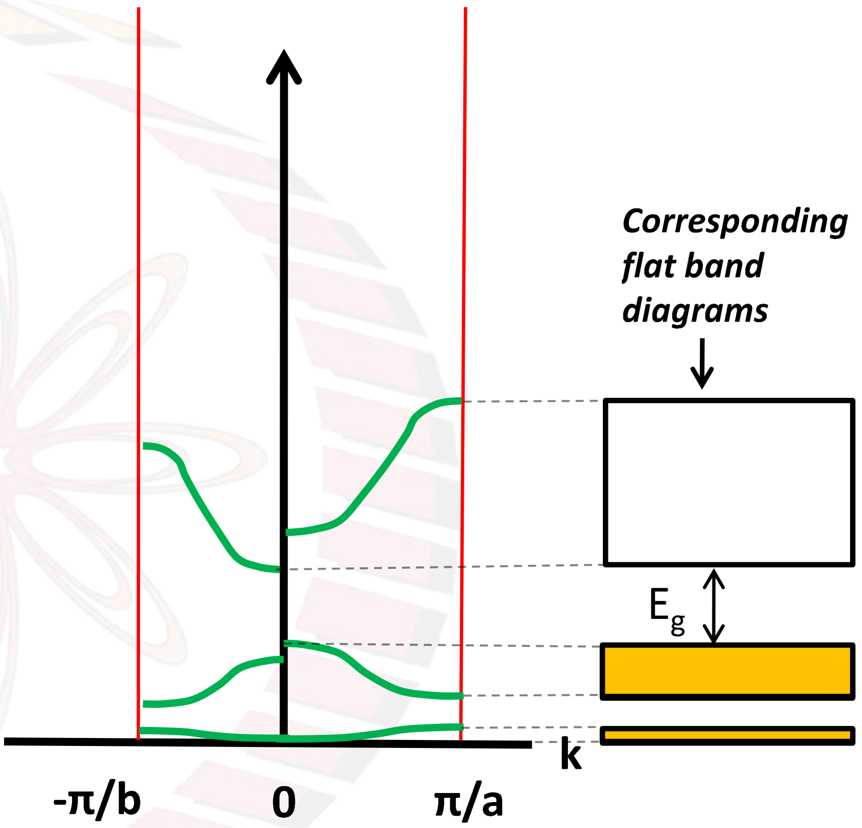
E Vs k of nearly free electrons, without accounting for the Brillouin Zones

E Vs k of nearly free electrons, distorted due to interaction with Brillouin Zones

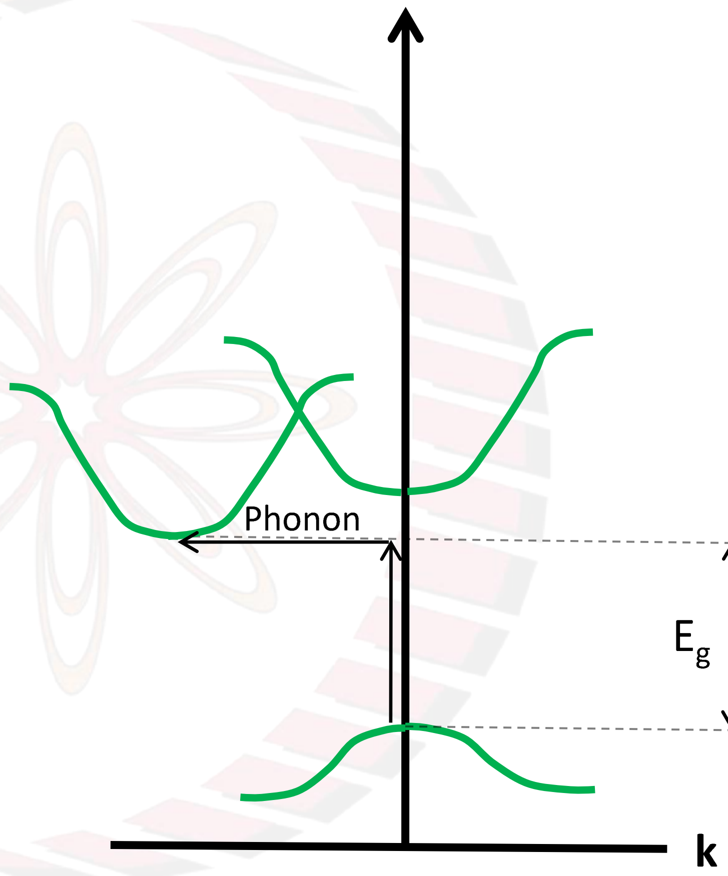
Brillouin zone boundaries



Direct bandgap semiconductor



Indirect bandgap semiconductor


Phonon
E_g
k

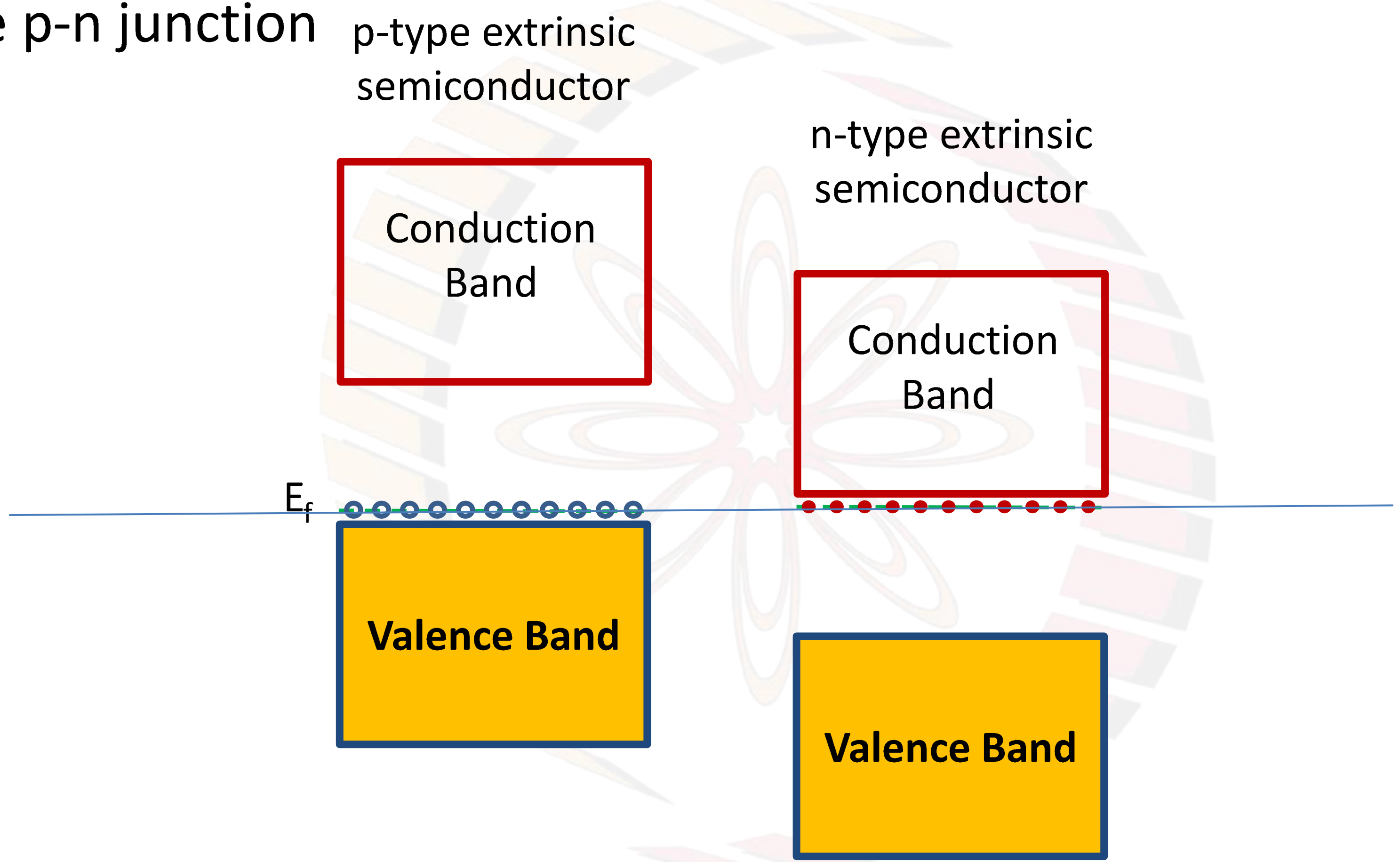
Conclusions:

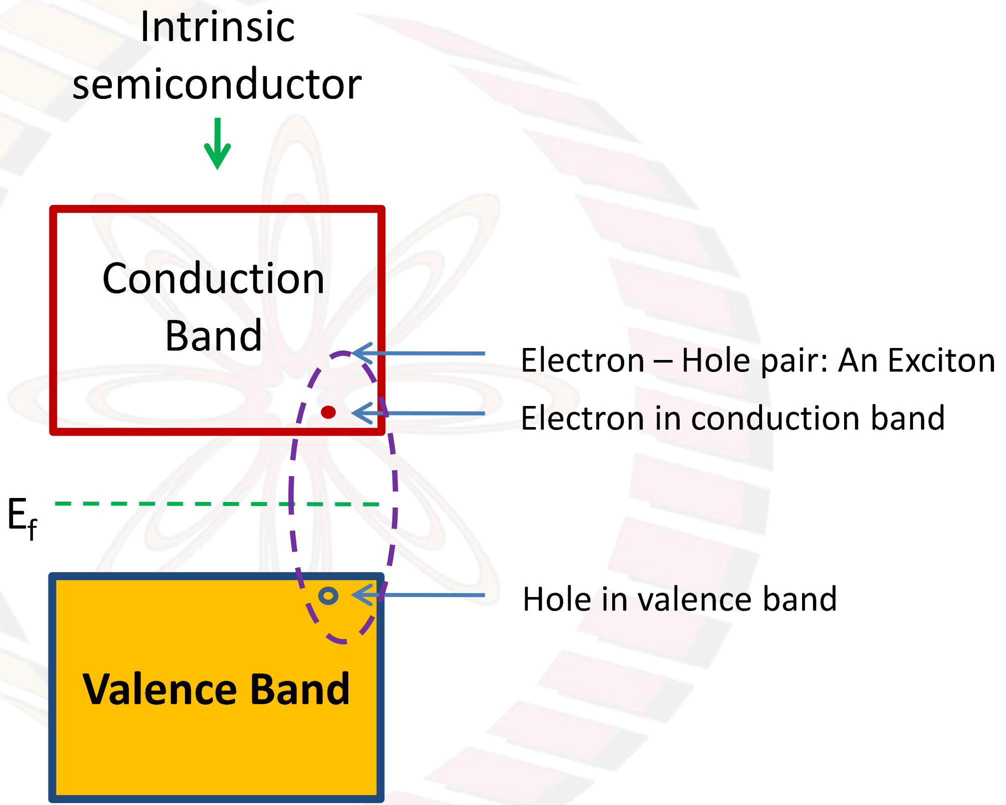
1) There is significant variation in the band diagrams of different types of materials
2) Interaction of a material with radiation depends strongly on its band diagram
3) Visible spectrum is a small fraction of solar radiation
4) There is a difference in the effectiveness with which direct and indirect bandgap semiconductors interact with radiation

Learning objectives:

1) To plot the band diagrams of photovoltaic cells
2) To explain the functioning of photovoltaic devices based on their band diagrams

The p-n junction




Intrinsic semiconductor
Conduction Band
Electron – Hole pair: An Exciton
Electron in conduction band
E_f
Hole in valence band
Valence Band