1D selective emitters optimization for TPV applications

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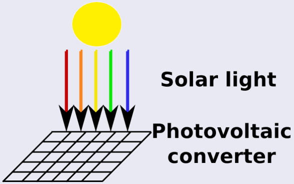
August 29^{th}, 2011

The purpose ?

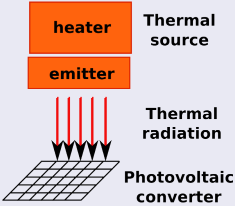
- Control thermal radiation
- Adapt it to energy converters to increase efficiency

Photovoltaics



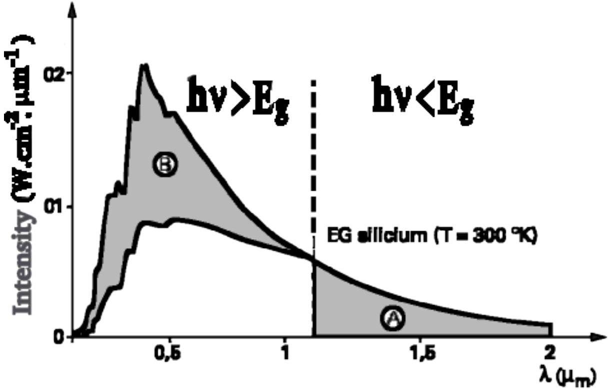
Visible light

Thermo-photovoltaics



Infrared radiation

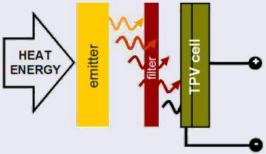
Main loss mechanisms



Losses du to transmission (A) and incident photons excess of energy (B) (Jean-Claude MULLER, Techniques de l'ingenieur, 2007)

Possible solutions

Filtering

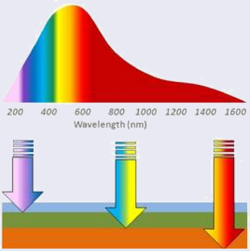


(www.cam.uh.edu)

$\Longrightarrow$ High conversion efficiency

$\Longrightarrow$ Non transmitted radiation is lost

Multijunction cells

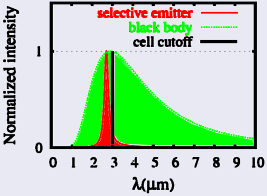


(thenakedscientists.com)

$\Longrightarrow$ Higher power and efficiency

$\Longrightarrow$ Complex and expensive cells

Selective emitters



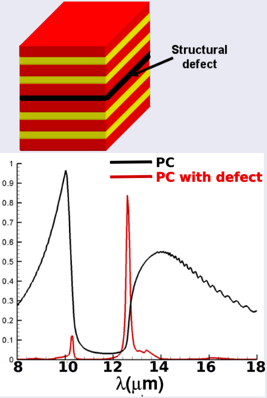
$\Longrightarrow$ Emission at $\lambda \lesssim \lambda_{bandgap}$

$\Longrightarrow$ All emitted photons are converted

$\Longrightarrow$ Low incident flux $\Longrightarrow$ Low Electric Power

Some spectrally coherent thermal sources 1/2

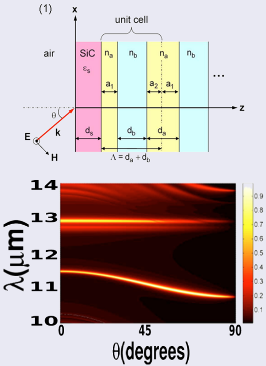
A PC with a defect



Hemispherical emittance

(Ben Abdallah and Ni, JAP, 97(2005))

A PC with a dielectric material

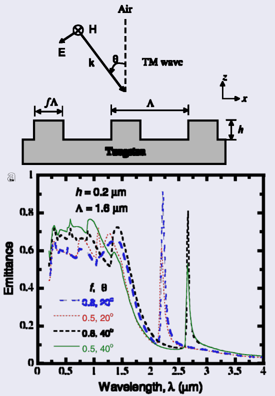


Spectral and directional emissivity

(Lee and Zhang, JHT, 129(2007))

Some spectrally coherent thermal sources 2/2

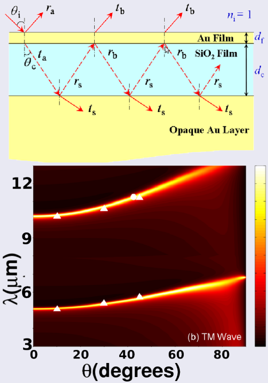
Surface gratings



Spectral Emittance

(Chen and Zhang, Opt. Com., 269(2007))

Fabry-perot like cavity

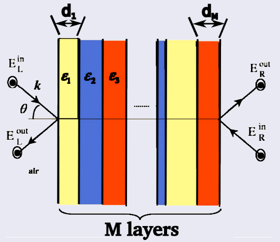


Spectral and directional emissivity

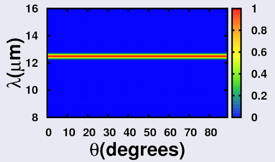
(Wang et al, IJHMT, 52(2009))

Problem to solve

Multilayer structure to optimize



Target Emissivity



Target reflectivity

- Energy conservation : $\rho + \alpha + \tau = 1$
- No transmission : $\tau = 0$
- Kirchhoff's law : $\alpha(\lambda, \theta) = \epsilon(\lambda, \theta)$

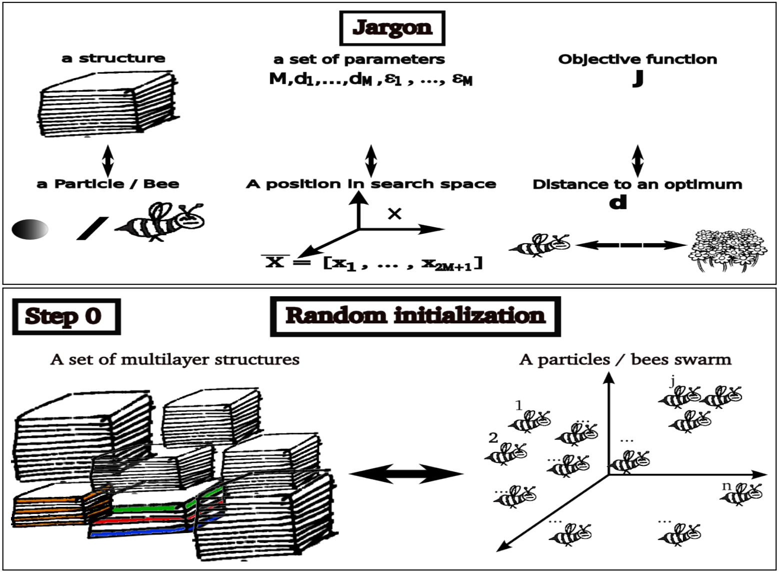
$$\Longrightarrow \rho_{target} = 1 - \epsilon_{target}$$

Quantity to minimize

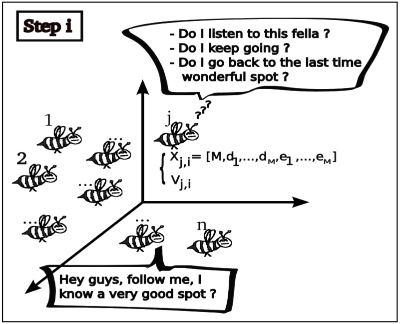
$$\begin{aligned} J &= \sum_p \int_{\theta_1}^{\theta_2} \int_{\lambda_{min}}^{\lambda_{max}} \left[\epsilon_{target}(\lambda, \theta) - \epsilon^p_{struc}(\lambda, \theta)\right]^2 d\theta\, d\lambda \\ &+ \sum_p \int_{\theta_1}^{\theta_2} \int_{\lambda_{min}}^{\lambda_{max}} \left[r_{target}(\lambda, \theta) - r^p_{struc}(\lambda, \theta)\right]^2 d\theta\, d\lambda \end{aligned} \quad (1)$$

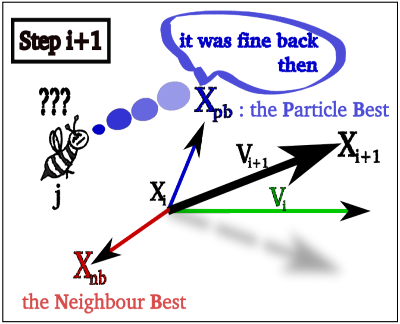
- Matrix Transfer Method
- Parameters : $M,\ d_i, \epsilon_i\ (i \in [1..M])$

Particle Swarm Optimization 1/2



Particle swarm optimization 2/2





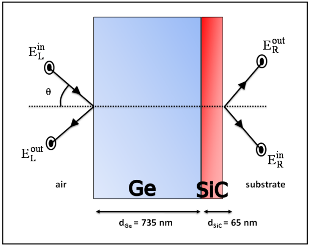
Position and Velocity update

$$X_{i+1} = X_i + V_i$$

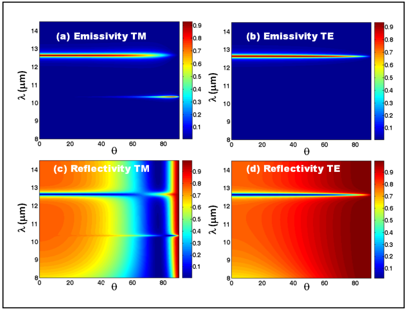
$$V_{i+1} = w_1 \cdot V_i + w_2 \cdot r_1 \cdot (X_{nb,i} - X_i) + w_3 \cdot r_2 \cdot (X_{pb,i} - X_i)$$

- w_k : Constant user defined weight factors
- r_k : Random weight factors

A Bilayer structure



(Drevillon et al., JAP, 109(2011))



Radiative Properties

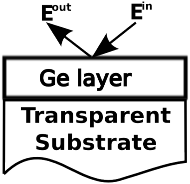
The structure features

- 735nm Ge layer + 65nm SiC layer
- Satisfying coherence properties (a peak around $\lambda = 12.6\mu$m)
- Simplest structures up to now

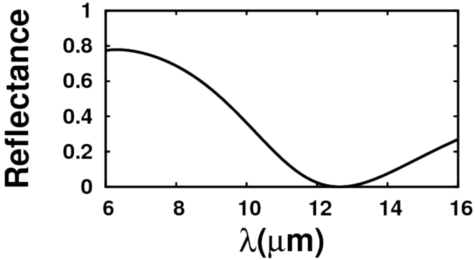
Physical phenomena

- Ge layer(transparent) : Anti reflection coating at λ_{peak}
- SiC layer(lossy) : High absorber/emitter at λ_{peak}

Bilayer structure : physical phenomena

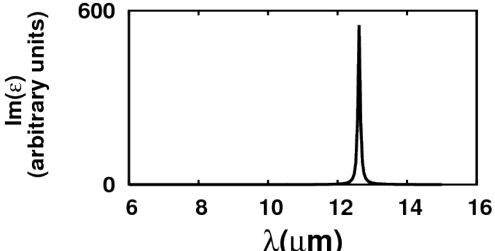


Anti-reflection coating

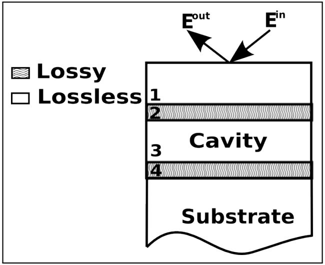


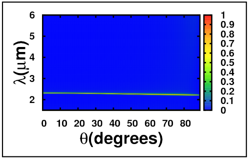
+

A lossy material : Silicon Carbide

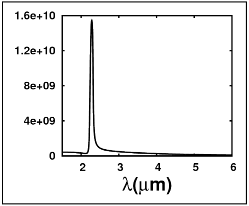


A four-layer structure





Emissivity (TM polarization)
Si(50nm)-Ag(30nm)-Si(300nm)-Ag(200nm)



Hemispherical emittance

Typical Features

- **Dimensions**
  - d_1 = 50nm (Si)
  - d_2 = 50nm (Ag)
  - d_3 from 300 to 500nm (Si)
  - d_4 = 200nm (Ag)
- **Materials : noble metals (lossy) and heavily doped semiconductors**

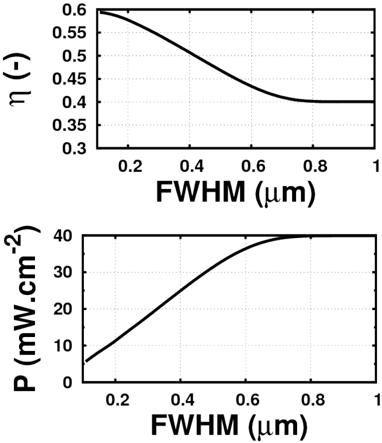
$\lambda_p \simeq 2.3\mu m$ and FWHM$\simeq 0.1\mu m$

Efficiency Vs Power

Simple cell model

- Total absorption
- Unity Quantum efficiency for photons with energy higher than E_g
- Only radiative recombinations (No RSH, No Auger recombinations)
- No modelization of the carriers transport
- No accounting for the cell temperature effects

(Shockley and Queisser, JAP, 32(1961))

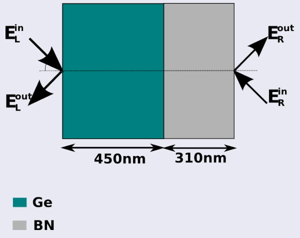


High powers ?

⇒ Emission peak (width) control

Tuning bilayers

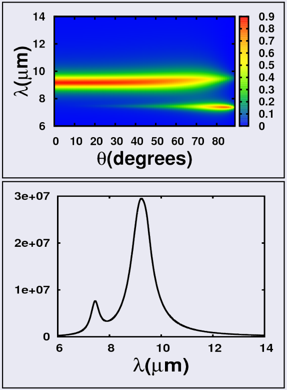
Ge-BN bilayer structure



- 450nm Ge layer + 310nm BN layer
- Materials
  - BN : lossy (Drude-Lorenz model for ϵ)
  - Ge : lossless ($n_{Ge} = 4$)

The emission peak tightly depends on ϵ_{lossy} resonance

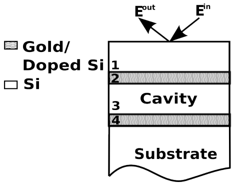
Radiative properties



Hemispherical Emittance

- $\lambda_{peak} \simeq 9.23\mu m \simeq \lambda_{\epsilon}$ *resonance*
- *FWHM* $\simeq 0.9\mu m$

Tuning 4-layer structures



* p-type doped Si $\leq 5.10^{20}$ cm^{-3}

n°	$\lambda_p(\mu m)$	$fwhm(\mu m)$	$\eta(-)$	$P(mW.cm^{-2})$
1	1.4	0.14		
2	1.76	0.15		
3	2.1	0.14		
4	1.8	0.1		
5	1.8	0.18		
6	1.8	0.36		

Table: Radiative properties and performances

materials	n°	$d_1(nm)$	$d_2(nm)$	$d_3(nm)$	$d_4(nm)$	$c_1(atom/cm^3)$
Si/Gold	1	87	36	150	390	–
	2	87	36	200	390	–
	3	87	36	250	390	–
Si / Doped Si	4	375	48	194	30	3.72
	5	375	48	194	30	2.72
	6	375	48	194	30	1.72

Table: Structures

An overview

Achieved Goals

- Design of simple quasi-coherent thermal sources at mid IR and tunable thermal sources at near IR
- Theoretical increase of TPV systems efficiency

In process

- Structures' samples fabrication
- Emissivity measurement experiments

Future developments

- Selective emitters behaviour at high temperature ?
- TPV systems performance measurement

Any questions ?

Thank you for your attention ?