# Package ‘planar’

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**Maintainer** Baptiste Auguie <baptiste.auguie@gmail.com>

**Title** Multilayer optics

**LinkingTo** Rcpp, RcppArmadillo

**Type** Package

**URL** https://github.com/baptiste/planar

**LazyLoad** yes

**License** GPL-3

**Description** Solves the electromagnetic problem of reflection and transmission of a plane wave or a gaussian beam, at a planar multilayer interface. Also computed are the decay rates and emission profile for a dipolar emitter near a multilayer structure.

**SystemRequirements** GNU make

**Version** 1.5.2

**VignetteBuilder** knitr

**Depends** methods, dielectric

**Imports** Rcpp, statmod, cubature, reshape2, plyr

**Suggests** ggplot2, Hmisc, grid, gridExtra, lattice, knitr, testthat

**RcppModules** planar, gaussian, collection

**Encoding** UTF-8

**Author** Baptiste Auguie [aut, cre] (Some functions ported from the original Matlab SPLAC code by E.C. Le Ru and P. G. Etchegoin),
Steven Johnson [aut, cph] (C code for the cubature library)

**NeedsCompilation** yes

**Repository** CRAN

**Date/Publication** 2014-08-16 22:56:57

# R topics documented:



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`planar-package` *planar*

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## Description

Multilayer optics

## Details

R/c++ implementation of the dipole emission near a planar multilayer stack

## Author(s)

baptiste Auguie <baptiste.auguie@gmail.com>

### References

Etchegoin, P. Le Ru, E., Principles of Surface-Enhanced Raman Spectroscopy, Elsevier, Amsterdam (2009).

L. Novotny, E. Hecht, Principles of Nano-optics Cambridge University Press, 2006

H. Raether. Surface Plasmons on Smooth and Rough Surfaces and on Gratings. Springer, 1988.

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## `classify` *classify*

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### Description

relabel factors

### Usage

```
classify(d, id = NULL, vars = NULL, ...)
```

### Arguments

| | |
|---|---|
| `d` | data.frame |
| `id` | column id |
| `vars` | variables |
| `...` | passed on to melt |

### Details

Wide to long format data.frame with new factor variable(s) describing the original columns

### Value

data.frame

### Author(s)

Baptiste Auguie

### See Also

Other helping_functions: `field_profile`, `lfief`; `internal_field`; `invert_stack`; `modify_levels` collection_ml *collection_ml*

## Description

Light intensity from the transmission of a bunch of plane waves at a planar interface

## Usage

```
collection_ml(xyz, wavelength = 632.8, omega = c(40, 50) * pi/180,
  psi = 0, epsilon = c(1.5^2, epsAg(wavelength)$epsilon, 1^2, 1^2),
  thickness = c(0, 50, 10, 0), maxEval = 3000, reqAbsError = 0,
  tol = 1e-04, progress = FALSE)
```

## Arguments

| | |
|---|---|
| `xyz` | position matrix |
| `wavelength` | wavelength |
| `omega` | collection angle |
| `psi` | polarisation angle |
| `epsilon` | vector of permittivities |
| `thickness` | thickness corresponding to each medium |
| `maxEval` | passed to cubature |
| `reqAbsError` | passed to cubature |
| `tol` | passed to cubature |
| `progress` | logical display progress bar |

## Details

Integration is performed over the solid angle defined by omega

## Value

data.frame intensity at the x, y, z position

## Author(s)

Baptiste Auguie

## dipole *dipole*

### Description

Dipole decay rates near a multilayer interface

### Usage

```
dipole(d = 1, wavelength, epsilon = list(incident = 1^2), thickness = c(0,
  0), qcut = NULL, rel.err = 0.001, Nquadrature1 = 1000,
  Nquadrature2 = 10000, Nquadrature3 = 10000, GL = FALSE,
  show.messages = TRUE)
```

### Arguments

| | |
|---|---|
| `d` | distance in nm |
| `wavelength` | wavelength in nm |
| `epsilon` | list of dielectric functions |
| `thickness` | list of layer thicknesses |
| `qcut` | transition between regions 2 and 3 |
| `rel.err` | relative error |
| `Nquadrature1` | maximum number of quadrature points in radiative region |
| `Nquadrature2` | maximum number of quadrature points in SPPs region |
| `Nquadrature3` | maximum number of quadrature points in dipole image region |
| `GL` | logical: use Gauss Legendre quadrature, or cubature::adaptIntegrate |
| `show.messages` | logical, display integration info |

### Details

dipole decay rates near a multilayer interface

### Author(s)

baptiste Auguie

## dipole_direct *dipole_direct*

### Description

Dipole total decay rate near a multilayer interface

### Usage

```
dipole_direct(d = 1, wavelength, epsilon = list(incident = 1^2),
  thickness = c(0, 0), Nquadrature1 = 50, Nquadrature2 = 200,
  Nquadrature3 = 50, qcut = NULL, qmax = Inf, show.messages = TRUE)
```

### Arguments

| | |
|---|---|
| `d` | distance in nm |
| `wavelength` | wavelength in nm |
| `epsilon` | list of dielectric functions |
| `thickness` | list of layer thicknesses |
| `Nquadrature1` | quadrature points in radiative region |
| `Nquadrature2` | quadrature points in SPPs region |
| `Nquadrature3` | quadrature points in dipole image region |
| `qcut` | transition between regions 2 and 3 |
| `qmax` | maximum q of region 3 |
| `show.messages` | logical, display integration info |

### Details

direct application of the textbook formula using integrand_mtot; performs poorly compared to the transformed version in `dipole`

### Author(s)

baptiste Auguie

## epsilon_dispersion *epsilon_dispersion*

### Description

epsilon_dispersion

### Usage

```
epsilon_dispersion(epsilon, wavelength = seq(400, 1000))
```

### Arguments

| | |
|---|---|
| `epsilon` | list of real or complex values |
| `wavelength` | numeric vector |

### Details

apply a function to a range of wavelength and return dielectric function

### Value

list

### Author(s)

baptiste Auguie

## epsilon_label *epsilon_label*

### Description

epsilon_label

### Usage

```
epsilon_label(epsilon = list(3.5, 1, 3, 1, "epsAu", 3, 3.5), names = NULL)
```

### Arguments

| | |
|---|---|
| `epsilon` | list of real or complex values |
| `names` | optional unique character names in order of appearance |

### Details

characterise the layers of a structure with unique labels for metals and dielectrics

### Value

factor

### Author(s)

baptiste Auguie

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## gaussian *Rcpp module: gaussian*

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### Description

Exposes C++ function integrand_gb

### Details

- integrand_gb integrand for gaussian beam excitation at a planar interface

### Examples

```
show( gaussian )
```

---

## gaussian_near_field_layer *gaussian_near_field_layer*

---

### Description

Electric field from the transmission of a gaussian beam at a planar interface

### Usage

```
gaussian_near_field_layer(xyz, wavelength = 500, alpha = 15 * pi/180,
  psi = 0, w0 = 10000, epsilon = c(1.5^2, epsAg(wavelength)$epsilon, 1^2),
  thickness = c(0, 50, 0), maxEval = 3000, reqAbsError = 0, tol = 1e-04,
  progress = FALSE, field = FALSE)
```

### Arguments

| | |
|---|---|
| `xyz` | position |
| `wavelength` | wavelength |
| `alpha` | beam incident angle |
| `psi` | beam polarisation angle |
| `w0` | beam waist radius |
| `epsilon` | vector of permittivities |
| `thickness` | thickness corresponding to each medium |
| `maxEval` | passed to adaptIntegrate |
| `reqAbsError` | passed to cubature |
| `tol` | passed to adaptIntegrate |
| `progress` | logical: display progress bar |
| `field` | logical: return the electric field (complex vector), or modulus squared |

### Details

Integration is performed over a spectrum of incident plane waves

### Value

data.frame electric field at the x, y, z position

### Author(s)

Baptiste Auguie

### See Also

Other gaussian_beam: `gaussian_near_field_ml`

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## `gaussian_near_field_ml` *gaussian_near_field_ml*

---

### Description

Electric field of a gaussian beam close to a planar interface

### Usage

```
gaussian_near_field_ml(xyz, wavelength = 632.8, alpha = 15 * pi/180,
  psi = 0, w0 = 10000, epsilon = c(1.5^2, epsAg(wavelength)$epsilon, 1^2,
  1^2), thickness = c(0, 50, 10, 0), maxEval = 3000, reqAbsError = 0,
  tol = 1e-04, progress = FALSE, field = FALSE)
```

## Arguments

| | |
|---|---|
| `xyz` | position matrix |
| `wavelength` | wavelength |
| `alpha` | beam incident angle |
| `psi` | beam polarisation angle |
| `w0` | beam waist radius |
| `epsilon` | vector of permittivities |
| `thickness` | thickness corresponding to each medium |
| `maxEval` | passed to cubature |
| `reqAbsError` | passed to cubature |
| `tol` | passed to cubature |
| `progress` | logical display progress bar |
| `field` | logical: return the electric field (complex vector), or modulus squared |

## Details

Integration is performed over a spectrum of incident plane waves using integrand_gb2

## Value

data.frame electric field at the x, y, z position

## Author(s)

Baptiste Auguie

## See Also

Other gaussian_beam: `gaussian_near_field_layer`

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`integrand_mtot` *integrand_mtot*

---

## Description

Total decay rate of a dipole near a multilayer interface

## Usage

```
integrand_mtot(d = 10, q, wavelength, epsilon = list(incident = 1.5^2, 1^2),
  thickness = c(0, 0))
```

## Arguments

| | |
|---|---|
| d | distance in nm |
| q | normalised in-plane wavevector in [0, infty) |
| wavelength | wavelength in nm |
| epsilon | list of dielectric functions |
| thickness | list of layer thicknesses |

## Details

Integrand without transformation of variables

## Author(s)

baptiste Auguie

## See Also

Other integrands dipole: integrand_nr1; integrand_nr2; integrand_nr3; integrand_rad

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# integrand_nr1 *integrand_nr1*

---

## Description

Dipole decay rates near a multilayer interface

## Usage

```
integrand_nr1(d = 10, u, wavelength, epsilon = list(incident = 1.5^2, 1^2),
  thickness = c(0, 0), GL = FALSE)
```

## Arguments

| | |
|---|---|
| d | distance in nm |
| u | transformed normalised in-plane wavevector sqrt(1-q^2) |
| wavelength | wavelength in nm |
| epsilon | list of dielectric functions |
| thickness | list of layer thicknesses |
| GL | logical: result formatted for use with Gauss Legendre quadrature |

## Details

Integrand of the dipole decay rates near a multilayer interface. Transformed part I1 (radiative) from u=0 to 1

### Author(s)

baptiste Auguie

### See Also

Other integrands dipole: integrand_mtot; integrand_nr2; integrand_nr3; integrand_rad

---

## integrand_nr2 *integrand_nr2*

---

### Description

Dipole decay rates near a multilayer interface

### Usage

```
integrand_nr2(d = 10, u, wavelength, epsilon = list(incident = 1.5^2, 1^2),
  thickness = c(0, 0), GL = FALSE)
```

### Arguments

| | |
|---|---|
| d | distance in nm |
| u | transformed normalised in-plane wavevector sqrt(q^2 - 1) |
| wavelength | wavelength in nm |
| epsilon | list of dielectric functions |
| thickness | list of layer thicknesses |
| GL | logical: result formatted for use with Gauss Legendre quadrature |

### Details

Integrand of the dipole decay rates near a multilayer interface. Transformed part I2 from u=0 to ucut

### Author(s)

baptiste Auguie

### See Also

Other integrands dipole: integrand_mtot; integrand_nr1; integrand_nr3; integrand_rad integrand_nr3    *integrand_nr3*

## Description

Dipole decay rates near a multilayer interface

## Usage

```
integrand_nr3(d = 10, u, ucut, wavelength, epsilon = list(incident = 1.5^2,
  1^2), thickness = c(0, 0), GL = FALSE)
```

## Arguments

| | |
|---|---|
| `d` | distance in nm |
| `u` | transformed normalised in-plane wavevector sqrt(q^2 - 1) |
| `ucut` | limit of the integral |
| `wavelength` | wavelength in nm |
| `epsilon` | list of dielectric functions |
| `thickness` | list of layer thicknesses |
| `GL` | logical: result formatted for use with Gauss Legendre quadrature |

## Details

Integrand of the dipole decay rates near a multilayer interface. Transformed part III from u=ucut to infinity

## Author(s)

baptiste Auguie

## See Also

Other integrands dipole: `integrand_mtot`; `integrand_nr1`; `integrand_nr2`; `integrand_rad`

## integrand_rad *integrand_rad*

### Description

Dipole decay rates near a multilayer interface

### Usage

```
integrand_rad(d = 10, angle, wavelength, epsilon = list(incident = 1.5^2,
  1^2), thickness = c(0, 0), GL = FALSE)
```

### Arguments

| | |
|---|---|
| d | distance in nm |
| angle | angle in radians |
| wavelength | wavelength in nm |
| epsilon | list of dielectric functions |
| thickness | list of layer thicknesses |
| GL | logical: result formatted for use with Gauss Legendre quadrature |

### Details

Integrand of the radiative dipole decay rates near a multilayer interface.

### Author(s)

baptiste Auguie

### See Also

Other integrands dipole: integrand_mtot; integrand_nr1; integrand_nr2; integrand_nr3

## internal_field *internal_field*

### Description

Internal field in a ML stack

### Usage

```
internal_field(wavelength = 500, angle = 0, psi = 0, thickness = c(0,
  20, 140, 20, 0), dmax = 200, res = 1000, epsilon = c(1^2, -12, 1.38^2,
  -12, 1.46^2), field = FALSE, ...)
```

### Arguments

| | |
|---|---|
| `wavelength` | wavelength |
| `angle` | angle |
| `psi` | polarisation angle (0 for TM) |
| `dmax` | maximum distance to interface |
| `thickness` | vector of layer thickness |
| `res` | resolution of sampling points |
| `epsilon` | permittivities |
| `field` | logical, return complex field vector, or modulus squared |
| `...` | further args ignored |

### Details

returns the electric field as a function of distance inside and outside of the structure

### Value

data.frame with position and electric field vector

### Author(s)

baptiste Auguie

### References

Principles of surface-enhanced Raman spectroscopy and related plasmonic effects

Eric C. Le Ru and Pablo G. Etchegoin, published by Elsevier, Amsterdam (2009).

### See Also

Other helping_functions: `classify`; `field_profile`, `lfief`; `invert_stack`; `modify_levels`

---

## `invert_stack` *invert_stack*

---

### Description

invert the description of a multilayer to simulate the opposite direction of incidence

### Usage

```
invert_stack(p)
```

### Arguments

| | |
|---|---|
| p | list |

### Details

inverts list of epsilon and thickness of layers

### Value

list

### Author(s)

Baptiste Auguie

### See Also

Other helping_functions: `classify`; `field_profile`, `lfief`; `internal_field`; `modify_levels`

---

## lfief *lfief*

---

### Description

Local field intensity enhancement factors in a multilayer

### Usage

```
lfief(wavelength = 500, angle = 0, polarisation = "p", thickness = c(0,
  20, 140, 20, 0), dmax = 200, res = 1000, res2 = res/10,
  epsilon = list(1^2, -12, 1.38^2, -12, 1.46^2), displacement = FALSE, ...)
```

### Arguments

| | |
|---|---|
| wavelength | wavelength |
| angle | angle |
| dmax | maximum distance to interface, if > layer thickness |
| thickness | vector of layer thickness |
| res | resolution of sampling points |
| res2 | resolution of sampling points outside stack |
| epsilon | list of permittivities |
| polarisation | polarisation |
| displacement | logical, Mperp corresponds to displacement squared (D=epsilon x E) |
| ... | further args passed to multilayer |

### Details

returns the LFIEFs as a function of distance inside and outside of the structure

### Value

long format data.frame with positions and LFEF (para and perp)

### Author(s)

baptiste Auguie

### References

Principles of surface-enhanced Raman spectroscopy and related plasmonic effects

Eric C. Le Ru and Pablo G. Etchegoin, published by Elsevier, Amsterdam (2009).

### See Also

Other helping_functions: `classify`; `internal_field`; `invert_stack`; `modify_levels`

---

## `modify_levels` *modify_levels*

---

### Description

relabel factors

### Usage

```
modify_levels(f, modify = list())
```

### Arguments

| | |
|---|---|
| `f` | factor |
| `modify` | named list |

### Value

factor

### Author(s)

Baptiste Auguie

### See Also

Other helping_functions: `classify`; `field_profile`, `lfief`; `internal_field`; `invert_stack`

## multilayer *multilayer*

### Description

Multilayer Fresnel coefficients

### Usage

```
multilayer(wavelength = 2 * pi/k0, k0 = 2 * pi/wavelength,
  angle = asin(q), q = sin(angle), epsilon = list(incident = 1.5^2, 1.33),
  thickness = c(0, 0), polarisation = c("p", "s"), d = 1, dout = d, ...)
```

### Arguments

| | |
|---|---|
| wavelength | [vector] wavelength in nm |
| k0 | [vector] wavevector in nm^-1 |
| angle | [vector] incident angles in radians |
| q | [vector] normalised incident in-plane wavevector |
| epsilon | list of N+2 dielectric functions, each of length 1 or length(wavelength) |
| thickness | vector of N+2 layer thicknesses, first and last are dummy |
| d | vector of distances where LFIEF are evaluated from each interface |
| dout | vector of distances where LFIEF are evaluated outside the stack |
| polarisation | [character] switch between p- and s- polarisation |
| ... | unused |

### Details

solves the EM problem of a multilayered interface

### Value

fresnel coefficients and field profiles

### Author(s)

baptiste Auguie

### References

Principles of surface-enhanced Raman spectroscopy and related plasmonic effects. Eric C. Le Ru and Pablo G. Etchegoin, published by Elsevier, Amsterdam (2009).

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`multilayercpp` *multilayercpp*

---

## Description

Multilayer Fresnel coefficients

## Usage

```
multilayercpp(wavelength = 2 * pi/k0, k0 = 2 * pi/wavelength,
  angle = asin(q), q = sin(angle), epsilon = list(incident = 1.5^2, 1.33),
  thickness = c(0, 0), polarisation = c("p", "s"), ...)
```

## Arguments

| | |
|---|---|
| `wavelength` | [vector] wavelength in nm |
| `k0` | [vector] wavevector in nm^-1 |
| `angle` | [vector] incident angles in radians |
| `q` | [vector] normalised incident in-plane wavevector |
| `epsilon` | list of N+2 dielectric functions, each of length 1 or length(wavelength) |
| `thickness` | vector of N+2 layer thicknesses, first and last are dummy |
| `polarisation` | [character] switch between p- and s- polarisation |
| `...` | unused |

## Details

solves the EM problem of a multilayered interface

## Value

fresnel coefficients and field profiles

## Author(s)

baptiste Auguie

## Examples

```
library(planar)
demo(package="planar")
```

`multilayerfull` *multilayerfull*

## Description

Multilayer Fresnel coefficients

## Usage

```
multilayerfull(wavelength = 2 * pi/k0, k0 = 2 * pi/wavelength,
  angle = asin(q), q = sin(angle), epsilon = list(incident = 1.5^2, 1.33),
  thickness = c(0, 0), psi = 0, z = 0, ...)
```

## Arguments

| | |
|---|---|
| `wavelength` | [vector] wavelength in nm |
| `k0` | [vector] wavevector in nm^-1 |
| `angle` | [vector] incident angles in radians |
| `q` | [vector] normalised incident in-plane wavevector |
| `epsilon` | list of N+2 dielectric functions, each of length 1 or length(wavelength) |
| `thickness` | vector of N+2 layer thicknesses, first and last are dummy |
| `psi` | [numeric] polarisation angle |
| `z` | [vector] positions to calculate the electric field intensity |
| `...` | unused |

## Details

solves the EM problem of a multilayered interface

## Value

fresnel coefficients and field profiles

## Author(s)

baptiste Auguie

`planar` *Rcpp module: planar*

## Description

Exposes C++ functions multilayer and recursive_fresnel

## Details

- multilayer reflection and transmission of a multilayer using a transfer matrix formalism
- recursive_fresnel reflection and transmission of a multilayer using recursive application of Fresnel coefficients

## Examples

```
show( planar )
```

`raman_shift` *raman_shift*

## Description

Raman shift

## Usage

```
raman_shift(wavelength = 632.8, shift = 520, stokes = TRUE)
```

## Arguments

| | |
|---|---|
| `wavelength` | wavelength (nm) |
| `shift` | Raman shift (cm-1) |
| `stokes` | logical Stokes or Anti-Stokes |

## Details

Raman shift conversion to absolute wavelength

## Value

wavelength of the Raman peak in nm

## Author(s)

Baptiste Auguie

## recursive_fresnel *recursive_fresnel*

### Description

Multilayer Fresnel coefficients

### Usage

```
recursive_fresnel(wavelength = 2 * pi/k0, k0 = 2 * pi/wavelength,
  angle = NULL, q = sin(angle), epsilon = list(incident = 1.5^2, 1.33^2),
  thickness = c(0, 0), polarisation = c("p", "s"))
```

### Arguments

| | |
|---|---|
| `wavelength` | [vector] wavelength in nm |
| `k0` | [vector] wavevector in nm^-1 |
| `angle` | [vector] incident angles in radians |
| `q` | [vector] normalised incident in-plane wavevector |
| `epsilon` | list of N+2 dielectric functions, each of length 1 or length(wavelength) |
| `thickness` | vector of N+2 layer thicknesses, first and last are dummy |
| `polarisation` | [character] switch between p- and s- polarisation |

### Details

computes the reflection coefficient of a multilayered interface

### Value

fresnel coefficients and field profiles

### Author(s)

baptiste Auguie

## recursive_fresnelcpp *recursive_fresnelcpp*

### Description

Multilayer Fresnel coefficients

### Usage

```
recursive_fresnelcpp(wavelength = 2 * pi/k0, k0 = 2 * pi/wavelength,
  angle = NULL, q = sin(angle), epsilon = list(incident = 1.5^2, 1.33^2),
  thickness = c(0, 0), polarisation = c("p", "s"))
```

### Arguments

| | |
|---|---|
| `wavelength` | [vector] wavelength in nm |
| `k0` | [vector] wavevector in nm^-1 |
| `angle` | [vector] incident angles in radians |
| `q` | [vector] normalised incident in-plane wavevector |
| `epsilon` | list of N+2 dielectric functions, each of length 1 or length(wavelength) |
| `thickness` | vector of N+2 layer thicknesses, first and last are dummy |
| `polarisation` | [character] switch between p- and s- polarisation |

### Details

computes the reflection coefficient of a multilayered interface

### Value

fresnel coefficients and field profiles

### Author(s)

baptiste Auguie

`transmission` *transmission*

## Description

transmission loss through a prism

## Usage

```
transmission(n, external, polarisation = "p")
```

## Arguments

| | |
|---|---|
| `n` | prism refractive index |
| `external` | external incident angle in radians |
| `polarisation` | polarisation |

## Details

transmission loss through a prism

## Value

transmission

## Author(s)

baptiste Auguie

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