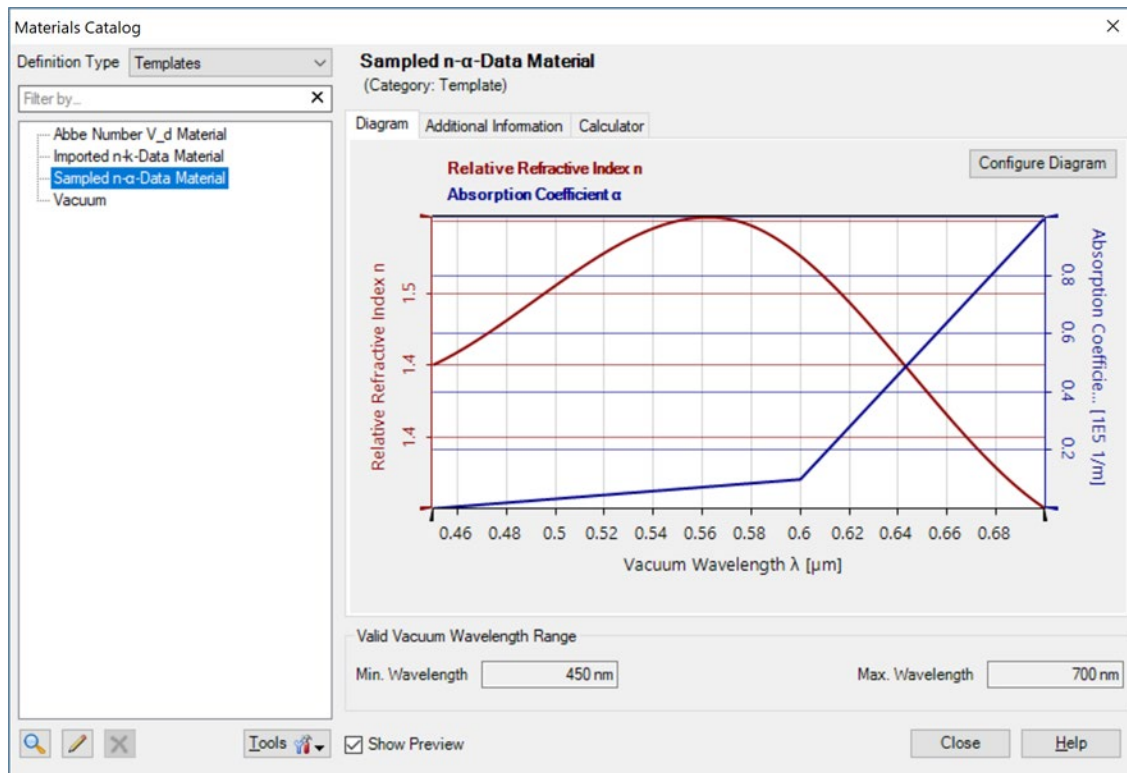


How to Work with the Programmable Material and Example (Linear Dependence)

Abstract



Providing maximum versatility is one of our most fundamental objectives. A key aspect of this aim is to provide a flexible-enough definition mechanism of the refractive index, in order to achieve a realistic characterization of the matter which composes an optical system. In VirtualLab Fusion this role is left to Materials and Media: the first deal with the dependence of the refractive index on wavelength (dispersion), the second group take care of the dependence on position. In what follows we present a tutorial that guides the user in the task of programming their own custom materials.

Where to Find the Programmable Material: Catalog (1)

1. Click on the 'Catalogs' menu in the top toolbar.

2. Click on the 'Materials' icon in the 'Catalogs' panel.

3. In the 'Materials Catalog' window, set 'Definition Type' to 'Templates'.

4. Click on the 'Vacuum' material in the list.

5. Click on the 'Edit' button at the bottom of the 'Materials Catalog' window.

6. In the 'Edit Material Data' dialog, click on the 'Programmable' option under 'Define Refractive Index by'.

7. Click on the 'Edit' button in the 'Definition' section of the 'Edit Material Data' dialog.

8. Click on the 'OK' button in the 'Edit Material Data' dialog.

Note that the Programmable Material is also accessible at any point during the construction of a system when a material must be entered for the configuration!

Snippet to define the real part of the refractive index

```
double RefractiveIndex = 1.0;
/***** INSERT YOUR CODE HERE *****/
return RefractiveIndex;
```

MinimumWavelength [double]
MaximumWavelength [double]
Wavelength [double]
Temperature [double]
GasPressure [double]

Refractive Index $n = \text{calc}(\lambda)$

Absorption Coefficient α [1/μm]

Domain of Definition
Vacuum Wavelength Range 10 pm to 100 μm

Usable Vacuum Wavelength Range 10 pm to 100 μm

Max. Wavelength 100 μm

Where to Find the Programmable Material: Catalog (2)

The image shows a software interface with several windows and panels. The 'Materials Catalog' window is the central focus, showing a list of materials with 'Vacuum' selected. The 'Edit Material Data' dialog is open, showing the 'Absorption Coefficient' tab with 'Programmable' selected. The 'Source Code Editor' contains a code snippet for defining the imaginary part of the refractive index. Red arrows and numbers 1-9 indicate the steps: 1. Click 'Catalogs' in the top menu; 2. Click 'Materials' in the catalog; 3. Select 'Templates' in the Definition Type dropdown; 4. Select 'Vacuum' in the materials list; 5. Click the 'Edit' button; 6. Click 'Absorption Coefficient' in the dialog tabs; 7. Click 'Programmable' in the 'Define Absorption Coefficient by' section; 8. Click 'alpha = calc(lambda)' in the 'Additional Information' section; 9. Click 'OK' in the dialog. A callout box on the right says: 'Note that the Programmable Material is also accessible at any point during the construction of a system when a material must be entered for the configuration!'. A red callout box at the bottom left says: 'Snippet to define the imaginary part of the refractive index'.

```
double AbsorptionCoefficient = 0.0;
/***** INSERT YOUR CODE HERE *****/
return AbsorptionCoefficient;
```

MinimumWavelength [double]
MaximumWavelength [double]
Wavelength [double]

alpha = calc(lambda)

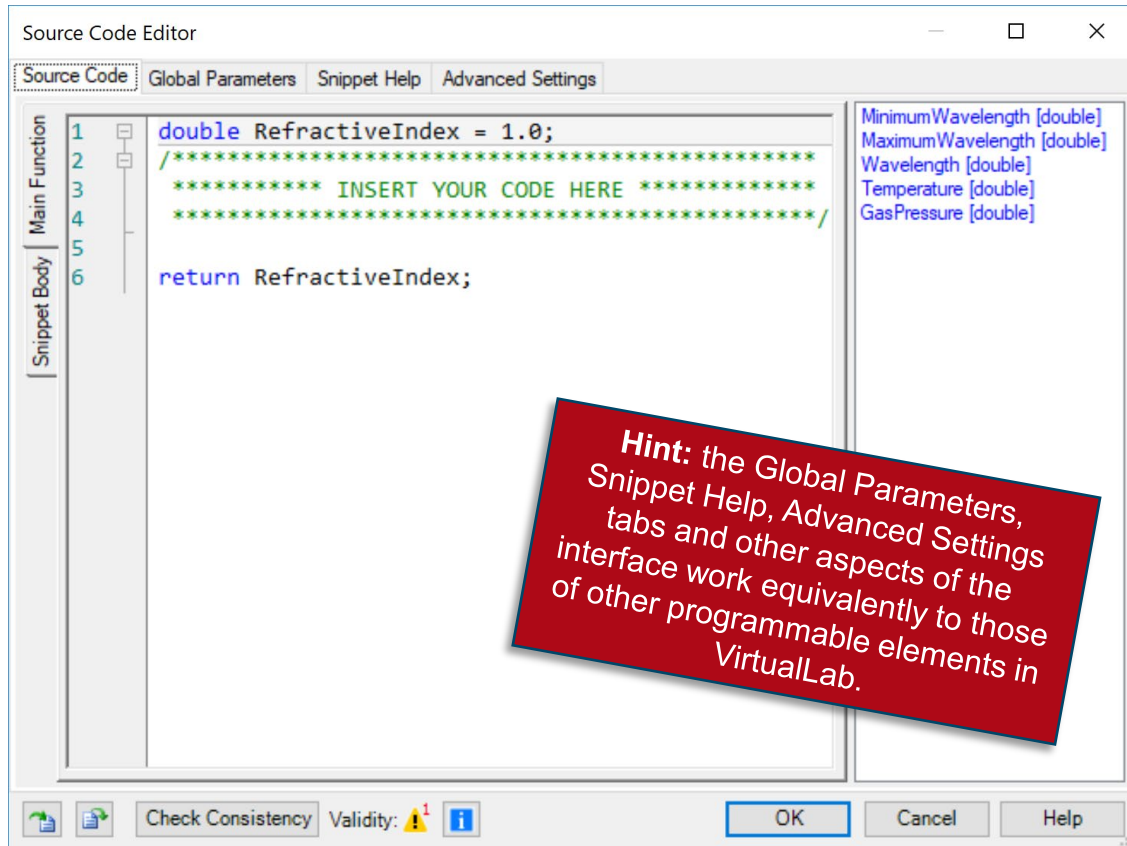
Domain of Definition
Wavelength Range: 10 pm to 100 μm

Max. Wavelength: 100 μm

Useable Vacuum Wavelength Range: 10 pm to 100 μm

Tools | Validity: ✓ | OK | Cancel | Help

Writing the Code: Refractive Index



- The refractive index is in general a complex value. This snippet defines its real part.
- The panel on the right shows a list of available independent parameters.
- **MinimumWavelength** and **MaximumWavelength** refer to the boundary values of the range in which this particular function is defined.
- **Wavelength** represents each of the points at which the programmed function is sampled.
- **Temperature** and **GasPressure** retrieve these values from the configuration dialogue, and they can be used in the code, in case the final value of the refractive index depends on them.
- The code must output a **double** value, representing the value of the real part of the refractive index at the wavelength **Wavelength** and for the given values of **Temperature** and **GasPressure**.

Writing the Code: Absorption Coefficient

- The refractive index is in general a complex value. This snippet defines the absorption coefficient α , which is related to the imaginary part of n via Eq. (1).
- The panel on the right shows a list of available independent parameters.
- `MinimumWavelength` and `MaximumWavelength` refer to the boundary values of the range in which this particular function is defined.
- `Wavelength` represents each of the points at which the programmed function is sampled.
- The code must output a `double` value, representing the value of the imaginary part of the refractive index at the wavelength `Wavelength`.

Source Code Editor

```
1 double AbsorptionCoefficient = 0.0;  
2 /*****  
3 ***** INSERT YOUR CODE HERE *****  
4 *****/  
5  
6 return AbsorptionCoefficient;
```

MinimumWavelength [double]
MaximumWavelength [double]
Wavelength [double]

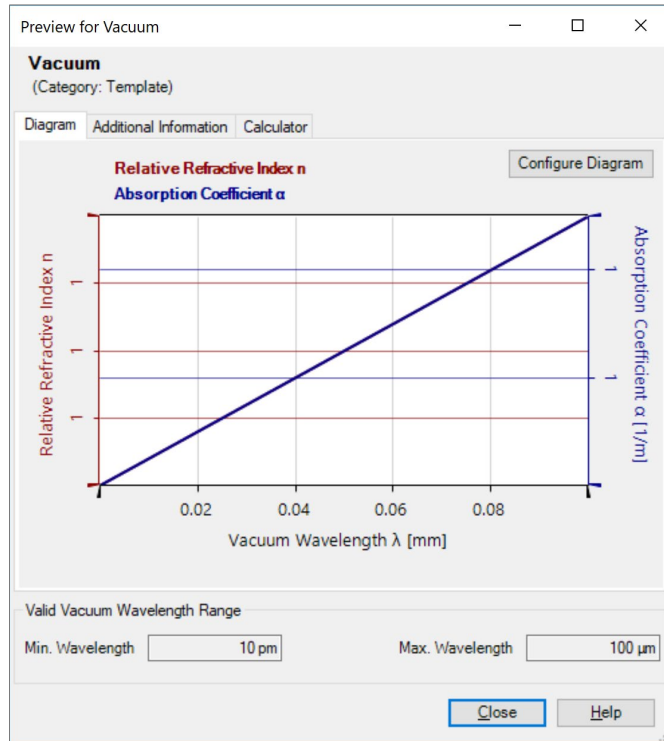
$$\tilde{n} = n + i n'$$
$$\alpha = \frac{4\pi n'}{\lambda_0} \quad (1)$$

Hint: the Global Parameters, Snippet Help, Advanced Settings tabs and other aspects of the interface work equivalently to those of other programmable elements in VirtualLab.

Check Consistency Validity: Help

Wavelength Range

If you wish the final value of the refractive index of your custom material to be defined with respect to another material, tick this option and select the reference material accordingly.



Edit Material Data

Material Name Vacuum

Refractive Index Absorption Coefficient Additional Information Temperature Data

Define Refractive Index by

Dispersion Formulas

Programmable $n = \text{calc}(\lambda)$

Sampled Dispersion

Constant

Data

Relative to Reference Material

Definition

Edit Validity:

Parameters

Slope 10 + 0.05 i Re Im A ϕ

OffsetAtMinimumWavelength 1 + 0 i Re Im A ϕ

Help

Domain of Definition

Vacuum Wavelength Range 10 pm to 100 μ m

Usable Vacuum Wavelength Range 10 pm to 100 μ m

Tools Validity: Ok Cancel Help

It is possible to combine a programmable real refractive index with, for instance, a constant absorption coefficient. Their snippets are defined independently (except for the user-defined global parameters)

Check the graphical representation of your custom material here!

Enter here the wavelength range for which your custom function will be valid

Programming a Material with Linear Behaviour

Linear Dependence of Refractive Index

Let us denote the complex-valued refractive index of our material with

$$\begin{aligned}\tilde{n}(\lambda) &= n(\lambda) + i n'(\lambda) \\ \alpha &= \frac{4\pi n'}{\lambda_0}\end{aligned}\tag{1}$$

and let us assume that both the real refractive index and the absorption coefficient exhibit a linear dependence on the wavelength

$$\begin{aligned}n(\lambda) &= n_0 + b\lambda \\ \alpha(\lambda) &= \alpha_0 + b_\alpha\lambda\end{aligned}\tag{2}$$

with

$n_0 \rightarrow$ Offset

$b \rightarrow$ Slope

$\alpha_0 \rightarrow$ Offset

$b_\alpha \rightarrow$ Slope

(3)

Where to Find the Programmable Material: Catalog (1)

The image illustrates the steps to find and edit a programmable material in a software catalog:

1. Click on the **Catalogs** menu in the top toolbar.
2. Click on the **Materials** icon in the Catalogs menu.
3. In the **Materials Catalog** window, set the **Definition Type** to **Templates**.
4. Select the **Vacuum** material from the list.
5. Click the **Edit** button at the bottom of the Materials Catalog window.
6. In the **Edit Material Data** dialog, select the **Dispersion Formulas** tab.
7. Select the **Programmable** option under **Define Refractive Index by**.
8. Click the **Edit** button in the **Definition** section.

The **Source Code Editor** shows the following snippet to define the real part of the refractive index:

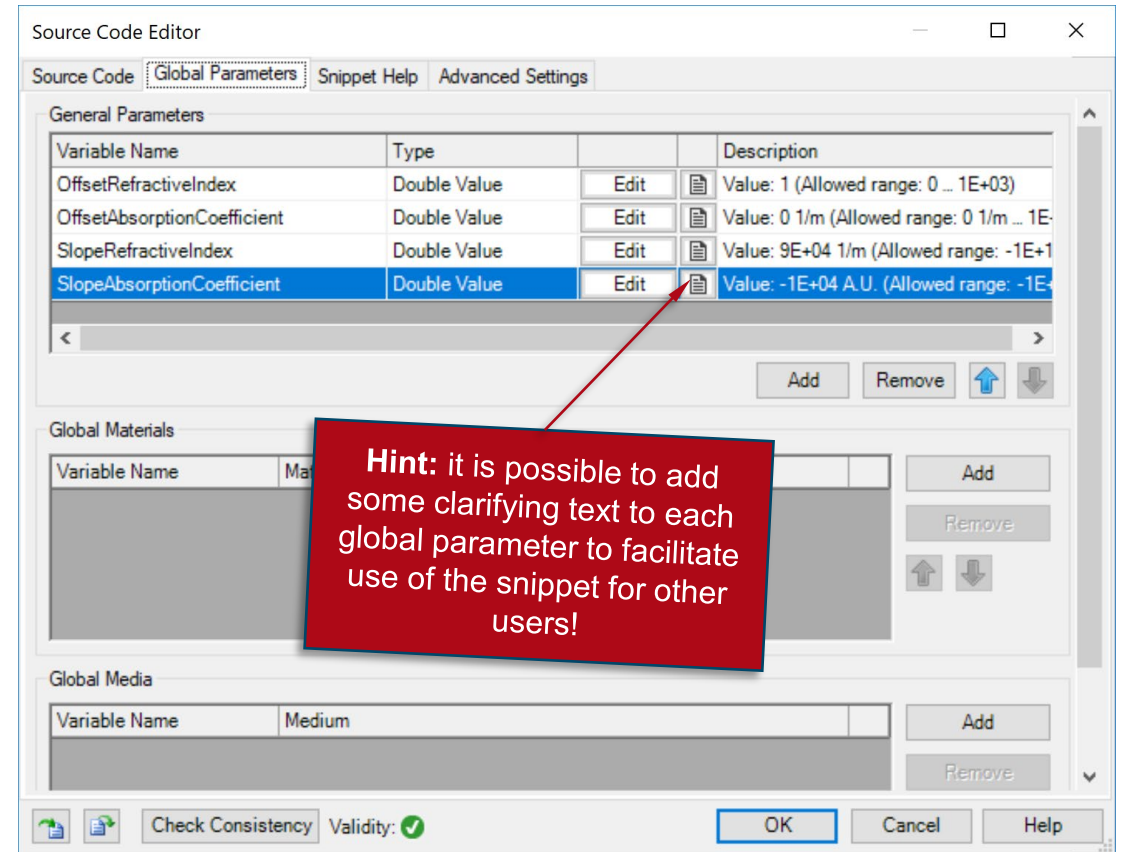
```
1 double RefractiveIndex = 1.0;  
2 /*****  
3 ***** INSERT YOUR CODE HERE *****/  
4 /*****  
5 *****  
6 return RefractiveIndex;
```

The **Edit Material Data** dialog shows the refractive index formula: $n = \text{calc}(\lambda)$. The **Domain of Definition** is set to **Vacuum Wavelength Range** from 10 pm to 100 μm.

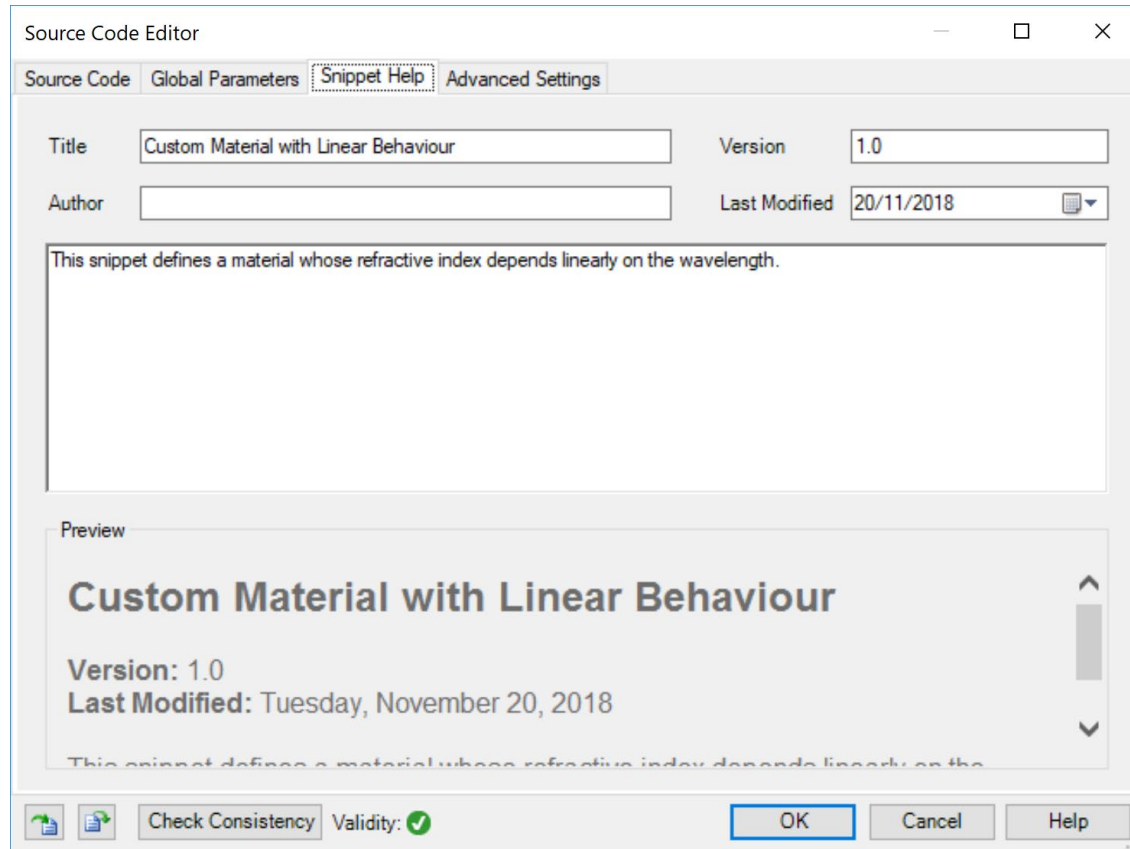
The **Absorption Coefficient α [1/μm]** graph shows a constant value of 0 across the wavelength range from 5 to 0.09 μm.

Programmable Material: Global Parameters

- Once you have triggered open the Edit dialogue, go to the Global Parameters tab.
- There, Add and Edit four global parameters:
 - `double` OffsetRefractiveIndex = 1A.U.: the offset for the linear dependence of the real part of the refractive index.
 - `double` OffsetAbsorptionCoefficient = 0A.U.: the offset for the linear dependence of the absorption coefficient.
 - `double` SlopeRefractiveIndex = 9e4A.U.: the slope for the linear dependence of the real part of the refractive index.
 - `double` SlopeAbsorptionCoefficient = -1e4A.U.: the slope for the linear dependence of the absorption coefficient.
- Use the button with the small “notes” icon to add some explanation to your custom global parameters.



Programmable Material: Snippet Help



- **Optional:** you can use the Snippet Help tab to write instructions, clarifications, and some metadata associated to your snippet.
- This option is very helpful to keep track of your progress with a programmable element.
- It is especially useful when the programmable element is later disseminated to be handled by other users!

Programmable Material: Snippet Help

The image shows two overlapping windows from a software interface. The top window is the 'Source Code Editor' with tabs for 'Source Code', 'Global Parameters', 'Snippet Help', and 'Advanced Settings'. It contains a form for editing a material snippet with fields for 'Title' (Custom Material with Linear Behaviour), 'Version' (1.0), 'Author', and 'Last Modified' (20/11/2018). A preview pane below shows a summary of the snippet. The bottom window is the 'Edit Material Data' dialog, currently on the 'Refractive Index' tab. It shows options to define the refractive index by 'Dispersion Formulas' (selected), 'Sampled Dispersion', or 'Constant'. The 'Programmable' option is selected, and the formula $n = \text{calc}(\lambda)$ is displayed. Below this are fields for 'Slope' (10) and 'OffsetAtMinimumWavelength' (1), along with buttons for 'ReIm' and 'Aphi'. A 'Help' button is highlighted with a red hand cursor. At the bottom, there are 'Domain of Definition' fields for 'Vacuum Wavelength Range' (10 μm to 100 μm) and 'Usable Vacuum Wavelength Range' (10 μm to 100 μm).

The 'Snippet Help' dialog box displays the following information:

Custom Material with Linear Behaviour

Version: 1.0
Last Modified: Tuesday, November 20, 2018

This snippet defines a material whose refractive index depends linearly on the wavelength.

PARAMETER	DESCRIPTION
OffsetRefractiveIndex	Offset for the linear dependence of the refractive index.
OffsetAbsorptionCoefficient	Offset for the linear dependence of the absorption coefficient.
SlopeRefractiveIndex	Slope of the linear dependence of the refractive index.
SlopeAbsorptionCoefficient	The slope of the linear dependence of the absorption coefficient.

Close

Programmable Material: Writing the Code (1)

Source Code Editor

Source Code Global Parameters Snippet Help Advanced Settings

Main Function

```
1 double RefractiveIndex = 1.0;
2
3 RefractiveIndex = OffsetRefractiveIndex + SlopeRefractiveIndex * Wavelength;
4
5
6 return RefractiveIndex;
```

Main Body

Snippet Body

MinimumWavelength [double]
MaximumWavelength [double]
Wavelength [double]
Temperature [double]
GasPressure [double]
OffsetRefractiveIndex [double]
OffsetAbsorptionCoefficient [double]
SlopeRefractiveIndex [double]
SlopeAbsorptionCoefficient [double]

Default global parameters/variables
Global parameters defined by user in Global Parameters tab

Eq. (2)

Are there errors in your code?

Export Snippet to save your work!

Check Consistency Validity: ✓

OK Cancel

Snippet to define the real part of the refractive index

Programmable Material: Writing the Code (2)

Declare output

```
1 double AbsorptionCoefficient = 0.0;  
2  
3  
4 AbsorptionCoefficient = OffsetAbsorptionCoefficient + SlopeAbsorptionCoefficient * Wavelength;  
5  
6 return AbsorptionCoefficient;
```

Eq. (2)

MinimumWavelength [double]
MaximumWavelength [double]
Wavelength [double]
OffsetRefractiveIndex [double]
OffsetAbsorptionCoefficient [double]
SlopeRefractiveIndex [double]
SlopeAbsorptionCoefficient [double]

Are there errors in your code?

Check Consistency Validity: ✓

Default global parameters/variables

Global parameters defined by user in Global Parameters tab

Export Snippet to save your work!

Snippet to define the absorption coefficient α

Save the Custom Material to the Catalog

The image shows two overlapping dialog boxes from a software interface. The primary dialog is titled "Edit Material Data" and is set to "Absorption Coefficient" mode. It features a "Material Name" field containing "CustomLinearMaterial". Under "Define Absorption Coefficient by", the "Absorption Formulas" radio button is selected, with a "Programmable" dropdown menu and a text area containing the formula $\alpha = \text{calc}(\lambda)$. Below this, the "Data" section includes a "Definition" field with an "Edit" button and a "Validity" indicator (green checkmark). The "Parameters" section contains four input fields: "OffsetRefractiveIndex" (value: h), "OffsetAbsorptionCoefficient" (value: 0 1/m), "SlopeRefractiveIndex" (value: 9E+04 1/m), and "SlopeAbsorptionCoefficient" (value: -1E+04 A.U.). At the bottom, the "Domain of Definition" section shows a "Wavelength Range" from 10 μm to 100 μm , and a "Usable Vacuum Wavelength Range" also from 10 μm to 100 μm . The "Ok" button at the bottom is highlighted with a red hand cursor. A secondary dialog titled "Name and Categories" is partially visible, showing a "Check" button and a list box containing "My Materials".

Hint: if you used the Catalog to define your custom material, you will be automatically prompted to save your work to the catalog

Output

The image displays a software interface for defining material properties. It is divided into three main sections:

- Edit Material Data:** Located on the left, it shows the material name set to "Vacuum". Under "Define Absorption Coefficient by", the "Absorption Formulas" option is selected with "Programmable" as the method. The "Domain of Definition" section shows a "Valid Vacuum Wavelength Range" with a "Min. Wavelength" of 10 pm. A red arrow labeled "1" points to the "Usable Vacuum Wavelength Range" field.
- Preview for Vacuum:** The central window shows a graph with two y-axes. The left y-axis is "Relative Refractive Index n " (ranging from 2 to 8) and the right y-axis is "Absorption Coefficient α [1/m]" (ranging from 0 to 0.8). The x-axis is "Vacuum Wavelength λ [mm]" (ranging from 0 to 0.1). A blue line represents the refractive index, and a red line represents the absorption coefficient. A red arrow labeled "2" points to the "Configure Diagram" button in the top right of the graph area.
- Configure Material Diagram:** A dialog box on the right allows for customizing the graph. It includes checkboxes for "Show Energy Dependence Instead of Wavelength Dependence", "Show Refractive Index", and "Show Absorption". Under "Show Absorption", the "Index κ " option is selected. A checkbox "Use Intersection of Valid Length Ranges" is checked. Below, there are sections for "Refractive Index Diagram" and "Absorption Diagram", each with a "Line Color" selector. A red arrow labeled "3" points to the "Use Intersection of Valid Length Ranges" checkbox. A red callout box with white text points to the graph area, stating: "Note the different functional dependence of α and κ (n')!".

Test the Code!

Main Function (Refractive Index)

```
// Declare output:  
double RefractiveIndex = 1.0;  
  
// Apply equation for linear dependence:  
RefractiveIndex = OffsetRefractiveIndex + SlopeRefractiveIndex * Wavelength;  
  
// Return output:  
return RefractiveIndex;
```

Test the Code!

Main Function (Absorption Coefficient)

```
// Declare output:  
double AbsorptionCoefficient = 0.0;  
  
// Apply equation for linear dependence:  
AbsorptionCoefficient = OffsetAbsorptionCoefficient + SlopeAbsorptionCoefficient * Wavelength;  
  
// Return output:  
return AbsorptionCoefficient;
```

Document Information

title	How to Work with the Programmable Material and Example (Linear Dependence)
document code	CZT.0103
version	1.0
toolbox(es)	Starter Toolbox
VL version used for simulations	7.4.0.49
category	Feature Use Case
further reading	- <u>How to Work with the Programmable Medium and Example (Thermal Lens)</u>