SpeCLED™

Spreading of Current in Light Emitting Diodes

Software for 3D Modeling of

Current Spreading and Temperature Distribution in LED chip

History Notes

2007

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1 Features Added in SpeCLED 3.0

1.1 Support of Current Blocking Layers

SpeCLED™ can now account for the current blocking by insulating layers made of dielectric materials which are formed between metallic electrodes and contact layers of an LED heterostructure to control the current pattern. Both n-blocking layer and p-blocking layer can be considered.

Geometry of the blocking layers should be specified using *N-Blocking Layer* and *P-Blocking Layer* tabs of the *Geometry* window, respectively.

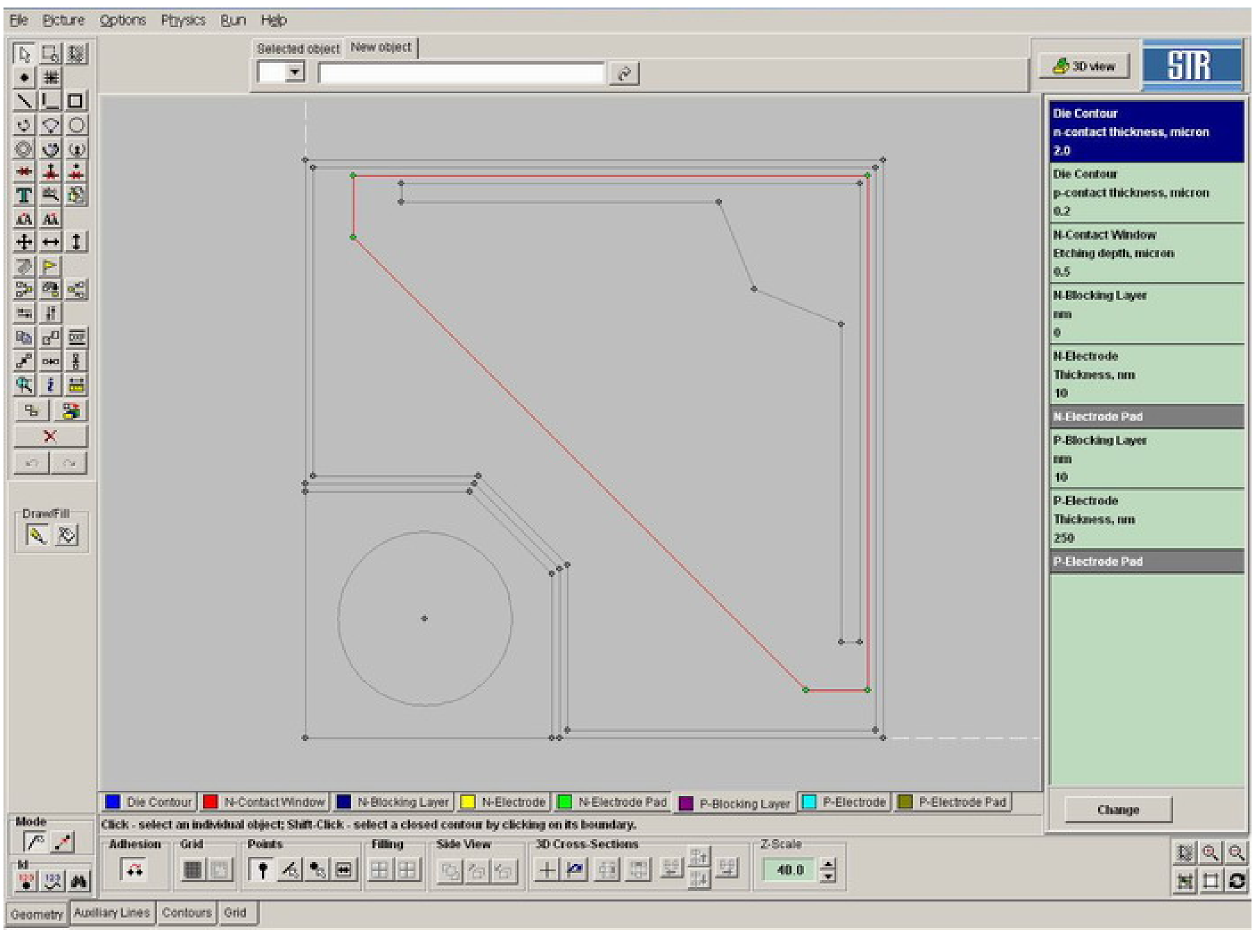


Fig. 1. Specification of p-blocking layer in Geometry window.

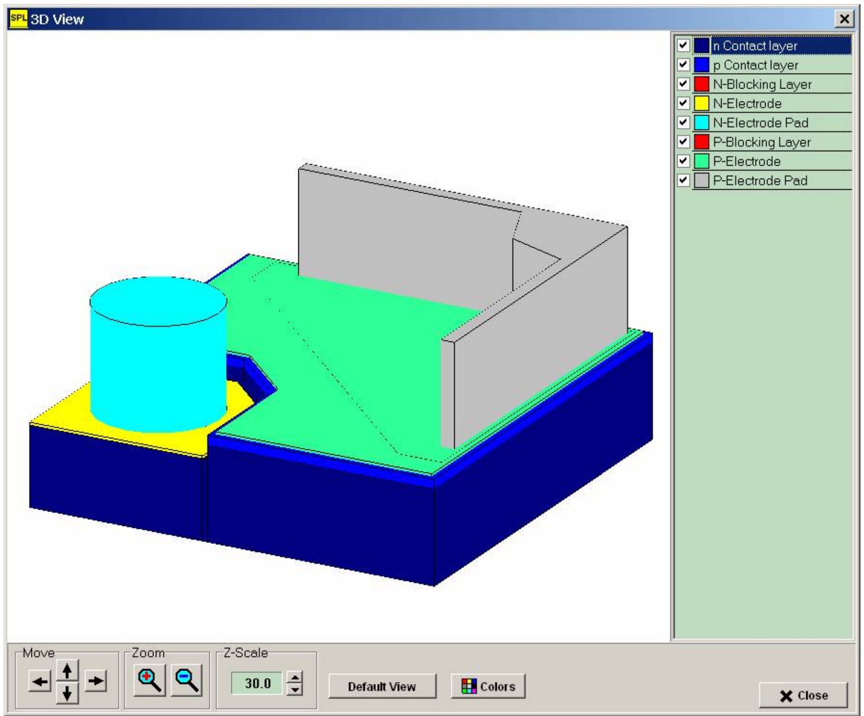


Fig. 2. 3D view of chip with p-blocking layer. All elements are shown

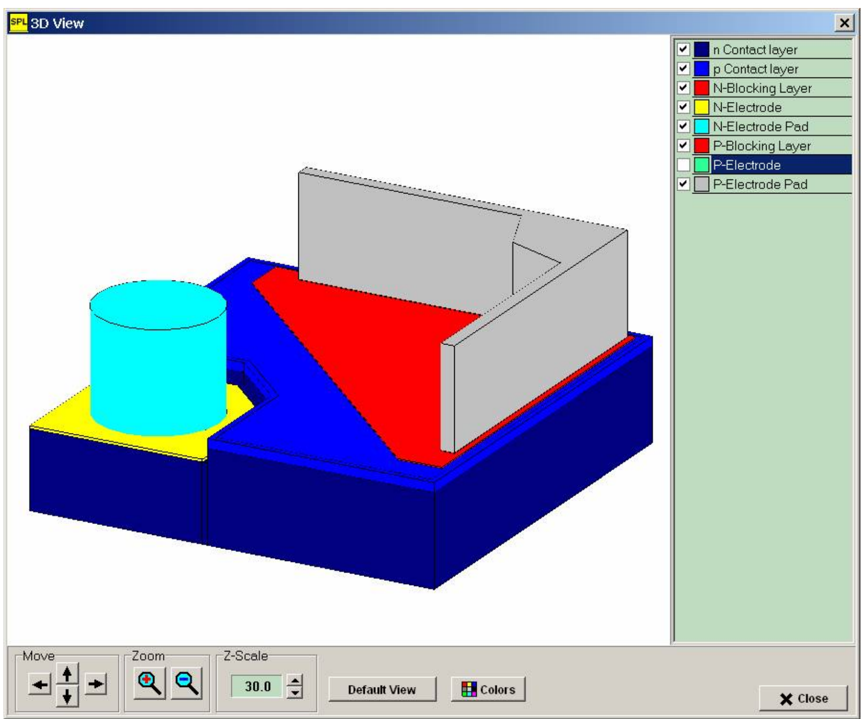


Fig. 3. 3D view of chip with p-blocking layer. P-electrode covering the p-blocking layer is hidden.

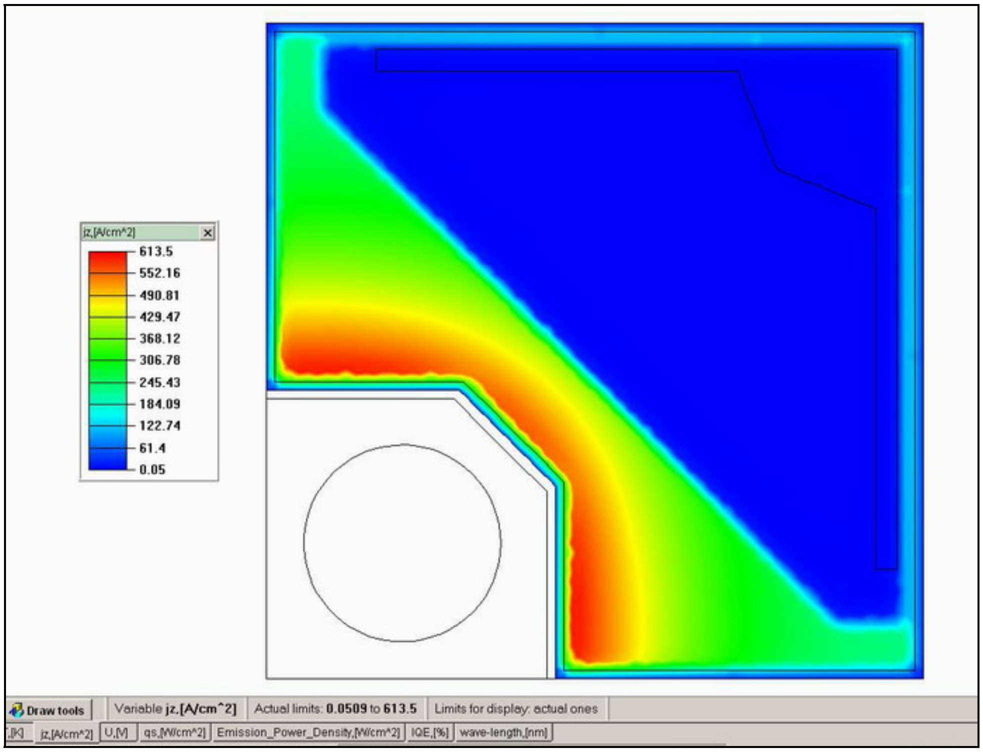


Fig. 4. Current distribution across the active layer. Chip with p-blocking layer.

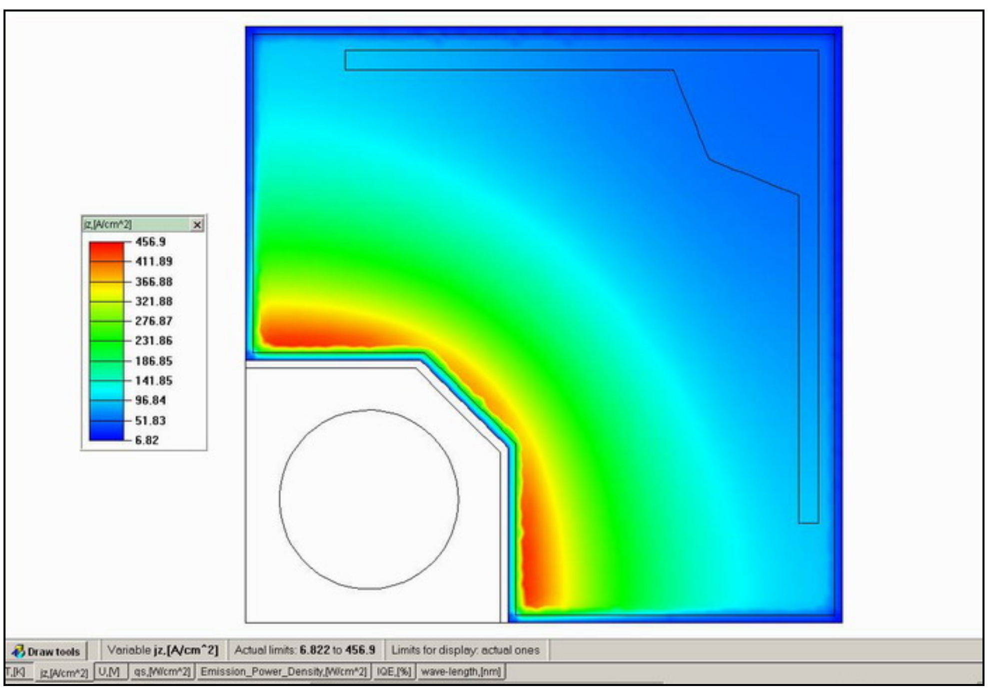


Fig. 5. Current distribution across the active layer. The same chip without p-blocking layer.

In addition to the current blocking by dielectric films, the implementation of a model of current spreading in the layers made of highly conductive semiconductor materials, like ITO, is under development. When it is finalized, the user will be able to assign either current blocking layer or current spreading layer under the p-electrode. This should be done using the same GUI element, the tab on the *Geometry* window named *P-Blocking Layer*. Selection of the actual type of this layer (i.e. blocking (dielectric) layer or spreading (highly conductive) layer) should be made in the *P-Blocking/Spreading Layer* tab of the *Physics* dialog window. In **SpeCLED™ 3.0,** the option *Blocking Layer* is only available in this dialog window.

1.2 Fixing Errors in SpeCLED Graphical User Interface

Several errors in SpeCLED Graphical User Interface have been fixed.

2 Features Added in SpeCLED 2.1

2.1 Import of the Die Geometry from DXF Files

As an alternative to the manual geometry specification, the die contours can be imported from a Drawing Exchange Format (DXF) used by the **AutoCAD™** graphic editor and most of other CAD systems.

SpeCLED™ can recognize the following DXF primitives:

- **`LINE`**
- **`POLYLINE`**
- **`CIRCLE`**
- **`ARC`**

If the initial CAD drawing includes some other CAD elements (Reference Blocks, Splines, etc.), it should be converted into the acceptable format prior to saving in a DXF file. In **AutoCAD™** the **`EXPLODE`** command should be used to convert all contours to the primitives listed above. Depending on the initial elements, this command should be applied once or several times consecutively, until all contours are formed by the appropriate elements.
Besides, before exporting a CAD drawing, the user should delete all irrelevant objects, such as fillings, hatchings, dimension lines, etc. It is also recommended to copy all relevant contours to a new file before saving it in DXF format to eliminate storage of the removed elements in the file.

All geometrical elements contained in the imported file are loaded in **SpeCLED™** program into one layer. Specification of the correspondence of different contours forming the die with the layers used in **SpeCLED™** can be made in two ways:

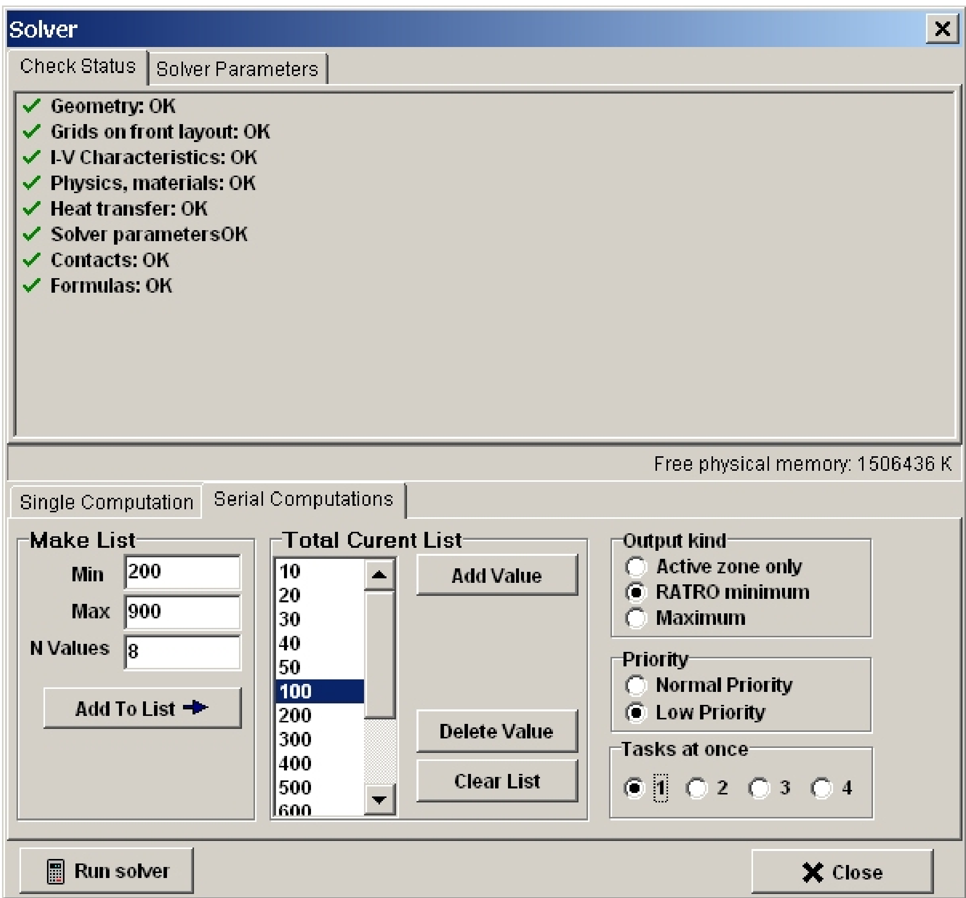
- The user can split the die geometry in the external tool used to create DXF file (e.g., **AutoCAD™**) prior to the exporting procedure. In this case, six individual DXF files should be created, each corresponding to a separate layer. Then the user should consecutively switch between layers in **SpeCLED™** and import the respective file to the current layer.

- The user can first import the whole die geometry specified in a single DXF file to one layer, e.g., Die Contour and then to move the contours to the corresponding layers using tools ***Move Lines to another Layer*** and ***Copy Lines from another Layer***.

2.2 Series computations

Series computation for a user-defined sequence of currents was implemented, while in the earlier versions the user was able to start a computation for a single value of current only which required a lot of computations to obtain a voltage-current characteristic.

The ***Solver*** dialog window allowing the user to start the computations contains the following items:



Single Computation tab allows the user to start a computation of the current spreading at a given total current. It contains the following parameter:

- ***Total Current*** text field allowing the user to assign the total current through the chip (in mA). The resulting current and temperature distribution corresponds to some calculated value of the total current that differs from the assigned *Total Current* not more than by a *Current Fitting Accuracy* value.

Serial Computations tab allows the user to start a sequence of computations of the current spreading for a wide range of total current, providing prediction of the whole I-V characteristics. It contains the following parameters:

- ***Make List*** section allows the user to assign an equidistant series of the total current values and add it to the list of currents. It contains the following items:
  - ***Min*** – the minimum current value.
  - ***Max*** – the maximum current value.
  - ***N Values*** – the number of values, including the ***Min*** and ***Max***. For example, specification of ***Min*** = 100, ***Max*** = 1000 and ***N Values*** = 10 creates the series 100, 200, 300 … 900, 1000.
  - ***Add To List*** button applies addition of the created series to the list of currents.
- ***Total Current List*** section contains the whole list of current sequence for which the computations should be carried out and the buttons ***Add Value***, ***Delete Value*** and ***Clear List***.
- ***Tasks At Once*** section specifies the number of simultaneously running computational processes. If value = 1 is specified, computation for a single value of current is run at a time. Each new computation is run automatically after the previous one is finished. If value exceeds 1, several computations are run simultaneously, which can be efficiently used on multi-CPU computers.

2.3 New IQE vs. Current Dependence

A new approximation of the dependency of the active region internal quantum efficiency on the total current was implemented. Unlike approximation used in the earlier versions, it involves physical heterostructure characteristics and accounts for the IQE dependence on temperature.

The relationship between internal quantum efficiency (IQE) η and current density j is approximated using a parametric setting as follows:

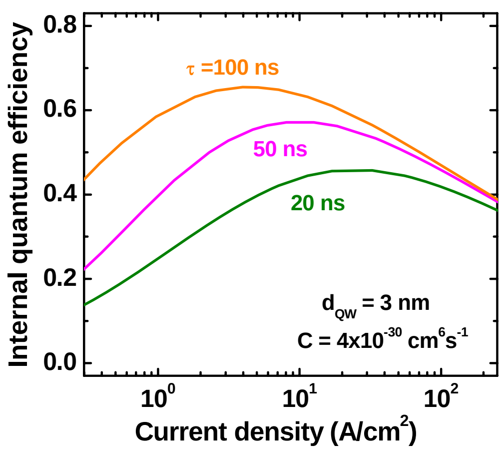
$$j(N) = qd \cdot \left(N/\tau + BN^2 (T/T_0)^{-3/2} + CN^3 (T/T_0)^{\gamma} \right)$$

$$\eta(N) = (qd/j) \cdot BN^2 (T/T_0)^{-3/2}$$

Here:

- N is the non-equilibrium carrier concentration in the active region
- q is the electron charge
- d is the active region thickness (in the case of MQW structure it is the total thickness of all quantum wells)
- τ is the non-radiative lifetime (typically equal to 20-100 ns)
- B is the radiative recombination rate constant at T_0 (typically equal to $2\text{-}3\times10^{-11}$ cm^{3}s^{-1})
- C is the Auger recombination coefficient at T_0 (typically equal to $1\text{-}10\times10^{-31}$ cm^{6}s^{-1})
- T_0 is the room temperature

This parametrization procedure produces the behavior of $\eta(j)$ similar to that observed experimentally and allows much more easier parameter fitting to measured external efficiency versus forward current.



2.4 Fixing Errors in SpeCLED Graphical User Interface

- An error arising at switching to electrode contour layer after removing of all lines on electrode pad layer
- An error arising at fast switching between different layers in GUI
- Several errors in the procedure of drawing of arcs
- An error with the range check of the *Mesa Depth* specification
- An error with displacement of lines occurring at copying contours to a different layer
- An error with automatic mesh generation in the geometries containing arcs

- A user-friendly diagnostics of the absence of computational mesh specified for both sides of the vertical structures at the start of the computation
- Acceleration of the user operation with complex die designs by reducing the number of operations followed by total geometry analysis
- Specification of individual color to each die layer in 3D View
- Automatic saving of the project file after start of the computation run

2.5 Fixing Errors in *SimuLEDView*

- An error arising at loading large number of active region files
- An error arising at switching between different planes

3 Features Added in SpeCLED 2.0

3.1 Vertical LEDs

In addition to planar LEDs, computation of the current spreading, light emission and heat transfer in multilayer vertical LED dice was implemented.

Before specification of the die geometry, the user should select the basic type of the LED geometry. The current version of **SpeCLED™** supports the following die types:

- Planar die (one-side electrode configuration). N-electrode and p-electrode are on the same side of the die, so that n-contact window is etched in the p-contact layer.
- Vertical die (two-side electrode configuration). N-electrode and p-electrode are on the opposite sides of the die.

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