Simulation of Silica Microlenslet Formation by Etch and Reflow Using *Elite* and *SSuprem4*

I. Introduction

In response to high demand, device designers are developing silica microlenslets that offer efficient coupling between optical fiber bundles and arrays of photodetectors, LEDs, or VCSELs. Microlenslet design involves precise control of the surface curvature in order to place the focus in the optimal region.

ATHENA, Silvaco's physically based process simulation software, helps device designers to simulate the entire fabrication sequence and to determine the effectiveness of the design through ray tracing and device simulation. The software also checks prospective designs and helps calibrate relevant material parameters with lenslet profiles that are easily imported from microscopy or raw calculations.

II. Device Operation

As an example, let's take a single photodetector with a surface-integrated silica microlenslet that forms a compact device with focusing and photon detection capabilities. The microlenslet collects the light signal from the optical fiber and focuses the light into the absorption region of the detector. The signal strength is the strongest at the focal point and so is the photogeneration rate. Consequently, the coupling efficiency and the sensitivity of the device are improved.

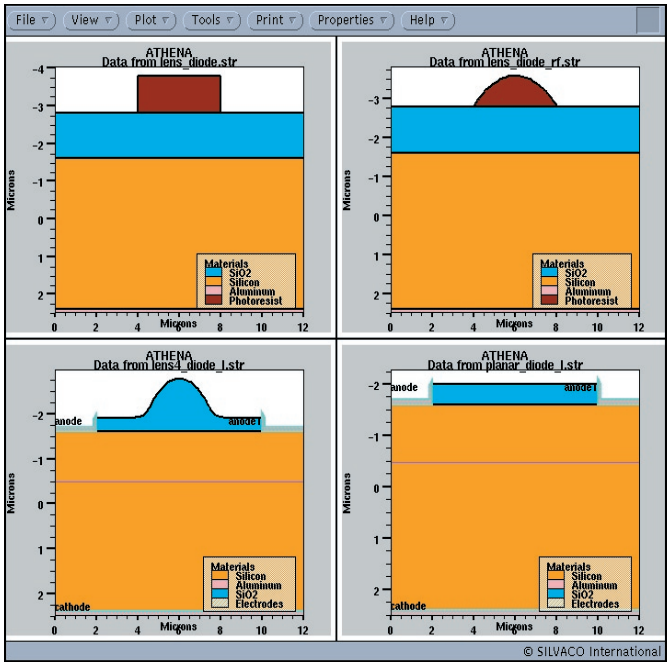

Figure 1. Microlenslet formation with SSuprem4.

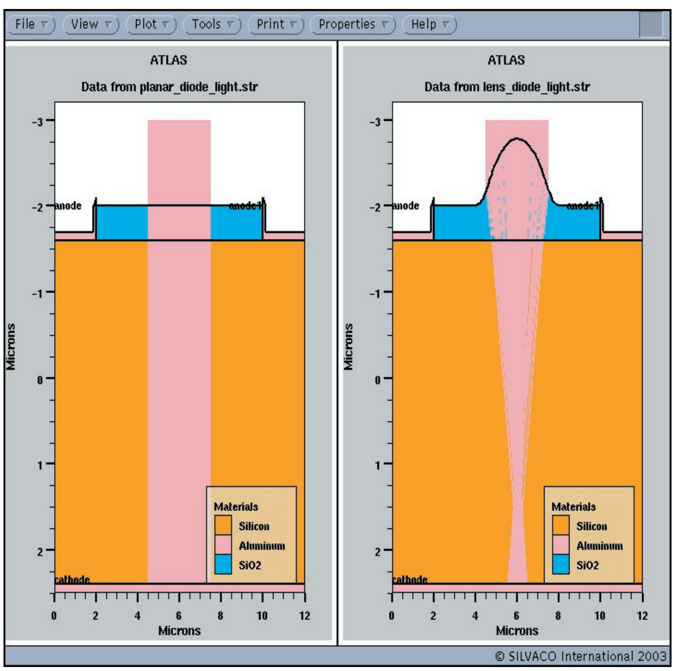

Figure 2. An optical beam with the ray tracing through the structure. The microlenslet is seen to focus the light within the silicon.

III. Device Fabrication Processes (*SSuprem4* and *Elite* required)

The simulated formation of this detector-lenslet device begins with the process simulation of the detector, including metal electrodes and a protective glass covering. The formation of the microlenslet in this example involves depositions, reactive ion etching, and a low-temperature reflow that has no effect on the underlying detector.

The starting point for lenslet formation is on top of the photodetector array after the overglass or planarization layer. At this point, a layer of silica that features the desired refractive index and appropriate thickness is laid down. A photoresist layer of the necessary thickness, viscosity, and surface tension properties covers the silica. The outline of the microlenslet is defined by exposing and removing the unwanted portion of the photoresist layer defines (Figure 1).

The next step is to anneal the structure so that the remaining portion of the photoresist is allowed to reflow and form a precisely shaped curved surface (Figure 1). The shape of this surface depends on the viscosity and surface tension of the photoresist layer relative to the silicon oxide layer, the reflow temperature, and the time. All of these parameters can be set with ***SSuprem4***, which then more accurately simulates this crucial step.

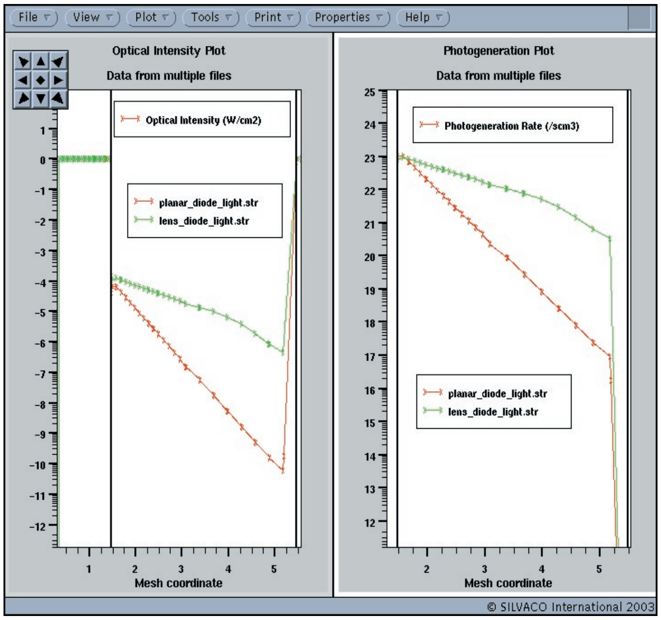

Figure 3. Optical intensity of the beam (left) and photogeneration rate (right) for both the planar device and a microlenslet device.

Following the anneal, reactive ion etching (RIE) will carve a replica of the photoresist into the silica. The precise shape of the silica lenslet depends on the difference between the etch rate in both the photoresist and in the silica. The final microlenslet shape is defined by using the ***Elite***-provided RIE model to separately set the etch parameters for the photoresist and silicon oxide.

Elite also simplifies surface profile definition by importing profile data in ASCII text format. These profiles are then used to shape the photoresist and silica layers. A designer calibrates the layers' relevant material parameters by comparing the simulated profiles with those taken from the microscopy of previous fabrication examples. A designer also auditions specific lenslet shapes with this approach.

A completed device is shown in Figure 1 and is compared with a photodetector without the microlenslet.

IV. Device Simulation and Ray Tracing (*S-Pisces* and *Luminous* required)

A reverse bias is applied to the anode of the photodetector both in the dark and under illumination for comparison. A beam representing the light signal from an optical signal source is shone overhead for the lighted simulation. A comparison of the beam shape and path within a detector with and without a microlenslet integrated onto it is easily obtained with the ray trace feature of ***Luminous*** (Figure 2). The microlenslet focuses the light onto the depletion region where photon absorption takes place. With a focused light beam, the signal intensity is concentrated to a smaller region (Figure 3), increasing the photogeneration rate within that region. This is verified by plotting the photogeneration rate along the middle line of both devices (Figure 3). The photogeneration rate in the depletion region of a photodetector with a microlenslet is much higher than that of the "planar" photodetector without a lenslet.

V. Conclusion

Silvaco's physically based process simulator ***ATHENA***, and its associated module ***Elite***, help to simplify of complicated and arbitrary surface profiles and lens curvature implementation. ***ATHENA*** and ***Elite's*** versatile features ease the workload of device designers and helps to exercise precise control of microlenslet device geometry.