



Fig. 8. Numerical microscope images of two rectangular scatterers buried inside the upper half space, under focused-beam illumination. (a) Refractive index map of the xy cross section at $z = 300$ nm. (b) The bright-field image of the structure, dominated by the light reflected from the interface. (c) The image with the reflection from the interface removed. This resembles the procedure followed in dark-field microscopy.

7. FDTD implementation: *Angora*

The focused-beam creation method described in this paper has been incorporated into our free, open-source FDTD software, *Angora* [28,29]. *Angora* is currently available for the GNU/Linux operating system. It supports full parallelization in all three dimensions, allowing it to be run easily on high-performance computing systems. *Angora* operates by reading a text-based configuration file that specifies all details of the simulation. The *Angora* binaries and configuration files used to generate the results in this paper can be found on the *Angora* website [30]. Please consult the README file in that directory for details.

8. Summary

In this paper, we described a method to synthesize a laser beam focused tightly into a focal area by an aplanatic converging optical system. The synthesis method is especially geared toward the finite-difference time-domain (FDTD) method. We expressed the focused beam as an infinite summation of plane waves, and used a finite combination of them to approximate the beam. This approach has the advantage that the plane-wave creation methods in FDTD are well researched and documented. For our implementation, we chose the total-field/scattered-field (TF/SF) method for creating a plane wave [1]. We discussed three different methods for approximating the beam as a finite sum of plane waves, and presented a comparative error analysis for these methods. We showed that good accuracy can be obtained with acceptable computational cost. We investigated the behavior of the focused beam in a two-layered space, and computed the numerical microscope images of weakly-scattering objects under focused-beam illumination. We also discussed possibilities for future improvement. Finally, we introduced our free, open-source FDTD software (*Angora*), which features the method described in this paper. The binaries and configuration files used for the examples in this paper have been made available on the *Angora* website [30].

Acknowledgments

This work was supported by the NIH grant R01EB003682 and the NSF grant CBET-0937987. The simulations in this paper were made possible by a supercomputing allocation grant from Northwestern University's *Quest* high-performance computing resource.