The Nanolithography Toolbox: Device design at the nanoscale

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Lithographic processing is fundamental to fabricating structures with nanoscale lateral dimensions. For example, the complex integrated circuits (IC) that make up modern semiconductor electronics are constructed from numerous overlaid nanostructures which are developed using lithography. The accuracy of the lithographic designs and the layout of the patterns are critical since it is the initial step of the lithographic process. Designs are generally implemented using several semiconductor-standard software packages, which generate graphic database system II (GDSII) files encoding planar geometrical shapes. The predominance of IC devices in manufacturing has led to these software packages being focused on designing and laying out integrated circuits, which typically have rectilinear geometries with edges intersecting at right angles. As a result, many of these software packages are not ideal for designing curved geometries with aggressively scaled dimensions for nanophotonic, nanoplasmonic, nanofluidic, and nanomechanical devices.

In order to deal with curved geometries at the nanoscale level in an efficient manner, we have developed a computer-aided design (CAD) software package for scripting and streaming complex shapes to GDSII. The Nanolithography Toolbox utilizes the freely available Java based (JGDS) library for encoding shapes to GDSII objects. The Toolbox consists of four sections, namely the graphical user interface (GUI), the machine resources, scripting, and programming. Using parameterized shapes as building blocks, the Toolbox allows users to rapidly design and layout nanoscale devices of arbitrary complexity through scripting and programming. The Toolbox offers many parameterized shapes, including structure libraries for micro- and nanoelectromechanical systems (MEMS and NEMS) and nanophotonic devices. Furthermore, the Toolbox allows users to precisely define the number of vertices for each shape or create vectorized shapes using Bezier curves. Parameterized control allows users to design smooth curves with complex shapes. The Toolbox is applicable to a broad range of design tasks in the fabrication of microscale and nanoscale devices.

Since its first public release in 2016, the Nanolithography Toolbox has continued to be developed. For example, hundreds of additional parametrized shapes have been created since its initial release. Figure 1 illustrates some of these new shapes. Furthermore, the user community has continued to utilize the Nanolithography Toolbox. Figure 2 highlights some of the recent structures created with the Nanolithography Toolbox. The platform-independent Nanolithography Toolbox runs on Linux, Windows and MacOS, and is free for users to download from the NIST website (https://www.nist.gov/services-resources/software/cnst-nanolithography-toolbox). A comprehensive manual can also be found at the same address.

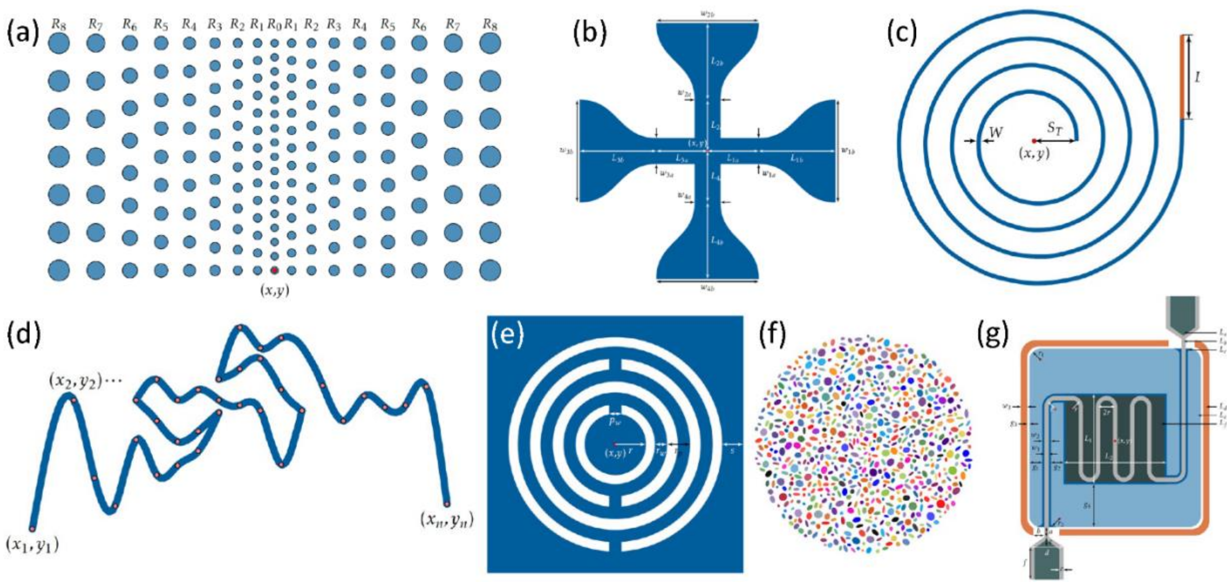

FIG. 1. Complex shapes generated using the Nanolithography Toolbox. Examples include (a) a double ramped array with linearly varying pitch and radius, (b) a funnel junction, (c) an Archimedean spiral, (d) a spline path, (e) a suspended ring array, (f) a random radial array, and (g) a microbolometer.

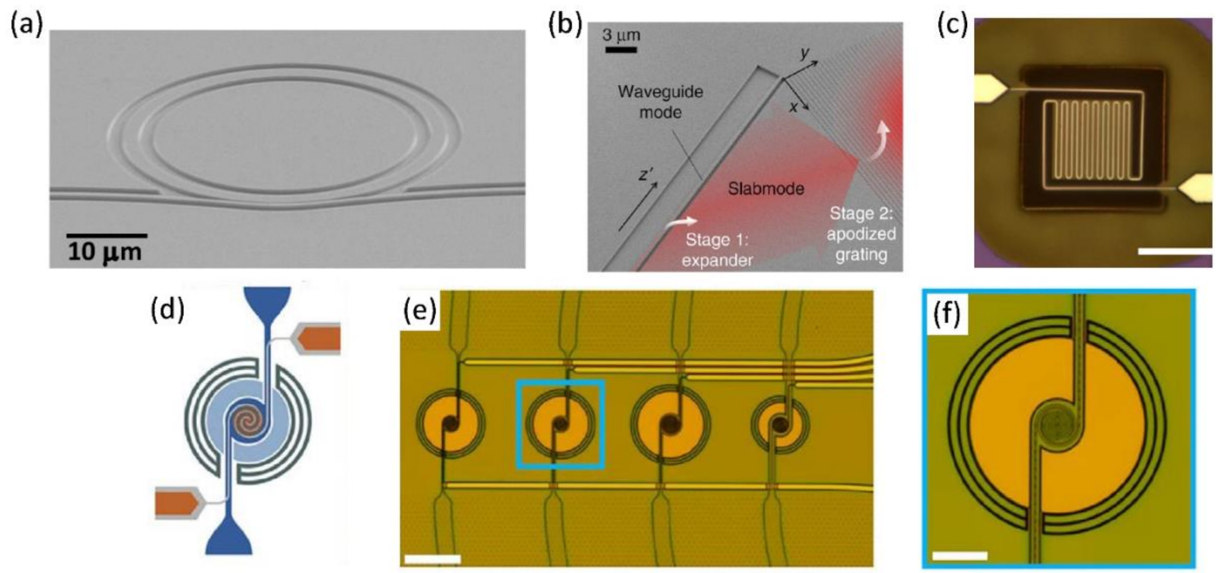

FIG. 2. Devices fabricated using the Nanolithography Toolbox. Examples include (a) a silicon nitride microring [1], (b) a photonic waveguide to free-space Gaussian beam extreme mode converter [2], (c) a microbolometer [3], and (d)-(f) a suspended fluidic channel with integrated spiral delay-line heaters.

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[2] S. Kim, *et al*, *Light: Science & Applications*. **7**, 72 (2018).
[3] V. Svatos, *et al*, *Infrared Physics & Technology*. **93**, 286-290 (2018).