Real-time fast reconfigurable grating for neutron and x-ray interferometry

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While spatial modulation of visible and ultraviolet light achieved substantial progress and made computational high-resolution microscopy feasible[1], efficient spatial modulation of neutron and x-ray beams remains a challenge due to their high transmission through most materials[2]. In this talk, we report on the development of a world-first on-demand reconfigurable modulator for neutron and x-ray beams. Such a device can be used as a fast reconfigurable source grating for phase imaging in far-field neutron and x-ray interferometry. Our DynAmic ReconfIgUrable Source grating (DARIUS) is a silicon microfluidic device that provides spatial modulation of the transmission of both neutron and x-ray beams. The spatial modulation is based on using microfluidic channels' structure and selectively infilling this structure with fluids that locally attenuate the transmission of neutrons and/or x-rays. DARIUS consists of three patterned 100 mm Si wafers that are aligned and bonded together: the "device" wafer and two "capping" wafers (Fig. 1). DARIUS' main component is the device wafer, which has a 51.2 × 51.2 mm^2 two-layer transmission grating patterned on the front and back faces of the wafer. This two-layer grating is formed by 5,120 microfluidic channels (2,560 channels on each side of the wafer) with 10 µm x 125 µm (width × depth) cross-section and 20 µm pitch. The front- and back-facing sub-gratings are laterally offset by half a pitch to provide a broad range of effective grating period tunability. The opacity of each of 5,120 channels can be switched independently between non-transparent and transparent states by filling/draining the channels with neutron/x-ray absorbing fluid. The infilling of the channels is done via programmable high-speed nanofluidic jetting. The dual-side patterned DARIUS can provide dynamic tuning of the effective transmission grating period from 20 µm to 20,000 µm. In this presentation, we report on the nanofabrication of the first prototype device, DARIUS-1.0 (Fig. 2), consisting of 128 independently controlled microfluidic channels, and device performance in x-ray beams. We also provide details on the fabrication progress of DARIUS-2.0 with 5,120 channels, wafer-scale bonding to seal the microfluidic channels, and selective infilling and draining of the opaque to neutron and x-ray fluid. Finally, we describe how DARIUS can be used for next-generation neutron interferometric microscopy currently being developed at NIST.

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[1] http://www.nobelprize.org/nobel_prizes/chemistry/laureates/2014/.
[2] Strobl, M. *et al.* Small angle scattering in neutron imaging – a review. *J. Imaging 2017, 3(4), 64*

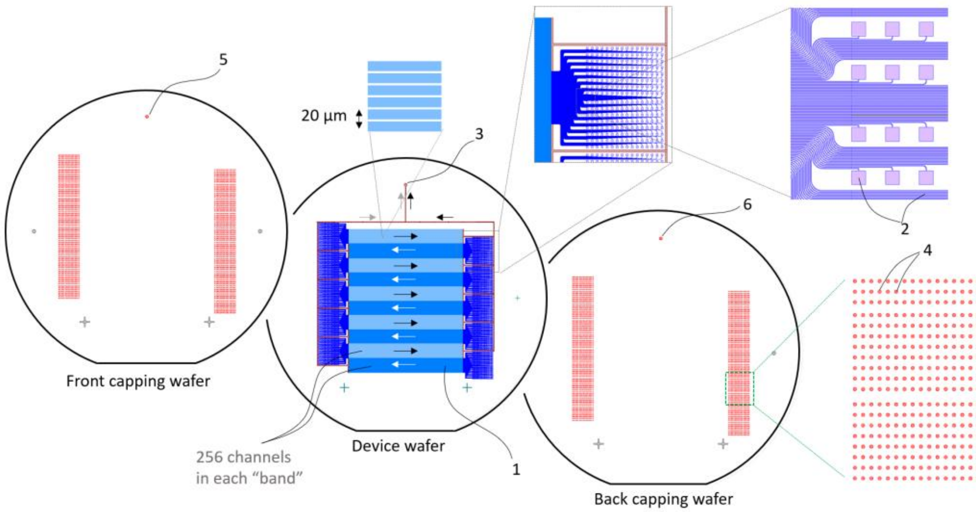

Figure 1. DARIUS 2.0 design: The main element of the DARIUS-2.0 is a "device" wafer which features on both sides of the wafer microfluidic channels (1), infilling routing lines and ports (2), and a common drain line (3). Transmission gratings on the front and back face are laterally offset by a half period to allow full tunability range of the effective period. The front- and back-face grating's duty cycles are different by design to take into account neutron beam divergence. Two front- and back- "caping" wafers each have 2,560 infilling wells (4) and common drain ports (5, 6).

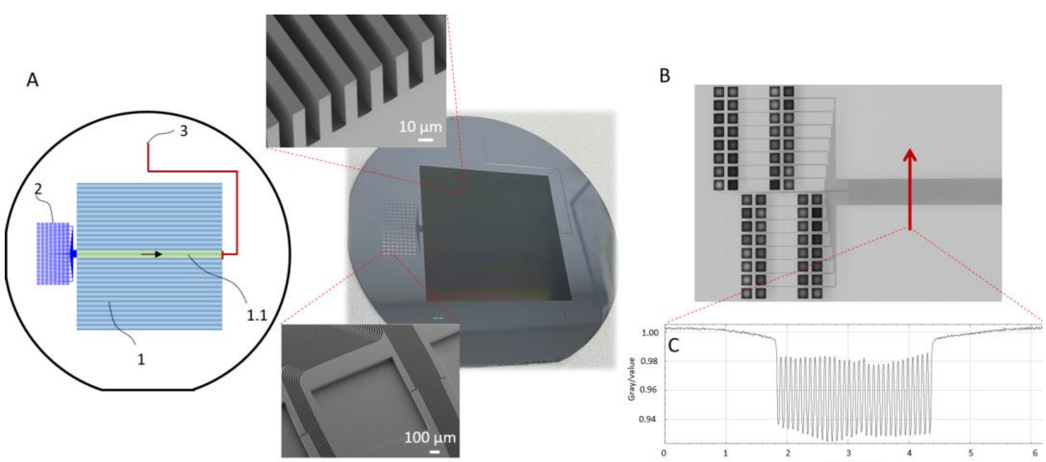

Figure 2: DARIUS 1.0: (A) Device layout with optical and SEM images. DARIUS-1.0 consists of 100 mm Si wafer pattered with 2,560 microfluidic channels (1), only 128 channels (1.1) are actively addressed via 128 filling ports and routing lines (2). The liquids are drained via common drain line 3. (B) X-ray normalized image when only 64 channels are infilled with x-ray absorbing liquid. (C) Line-scan across the channels shown on image (B).