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Laser nanofabrication deep inside silicon wafers

Rana Asgari Sabet[1,2], Aqiq Ishraq[1,2], Onur Tokel[1,2]

1. Department of Physics, Bilkent University, 06800 Ankara, Turkey
2. UNAM-National Nanotechnology Research Center and Institute of Material Science and Nanotechnology, Bilkent University, 06800 Ankara, Turkey

Abstract: Here, we introduce the first controlled nanofabrication capability in the bulk of silicon wafers. We exploit smart use of Bessel beams and demonstrate "**in-chip**" nano-structuring with features lower than 250 nm.

Silicon is at the heart of electronics and silicon-photonics. These industries are limited to creating functionalities on the wafer surface, which may be broadly classified as "on-chip". However, at the current state, much of the bulk (or subsurface) of the wafer is essentially wasted. Recently, we introduced a new fabrication approach, enabling "**in-chip**" capabilities, where we showed that infrared laser pulses can realize controlled 3-D modifications deep inside si, without damaging the wafer above or below modifications [1]. We further showed these can be used for introducing advanced functionality into the wafer, *e.g.*, waveguides or holograms, among others [1,2]. A critical milestone would be to tackle the resolution limit of fabrication, that is to **overcome the state-of-the-art 1-µm resolution limit** [1].

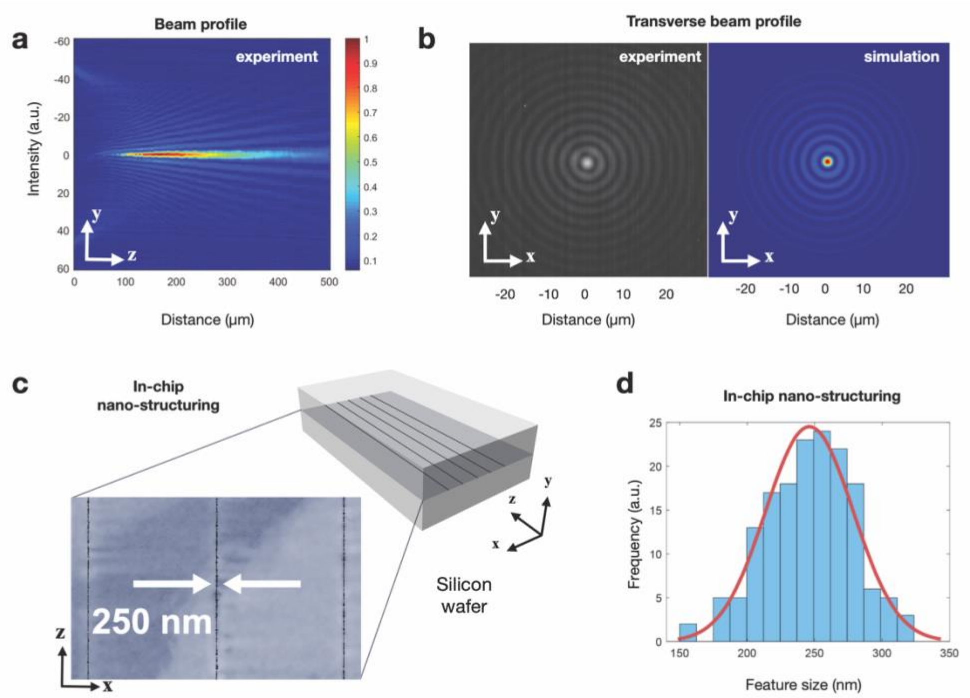

Fig. 1. a) Experimental characterization of the Bessel beam used for in-chip nano-structuring. **(b)** Experimental and theoretical transverse beam profiles. **(c)** Selective etching reveals nano-structures that formed with features of **250 nm**. **(d)** Histogram of the feature sizes of in-chip nano-structures.

Here, we demonstrate the first controlled nano-fabrication capability deep inside silicon wafers (**Fig.1**). We exploit a spatially structured laser beam (**Fig 1a - 1b**), created with a spatial light modulator (SLM). With the **smart use** of spatial beam profiling, we achieve creation of controlled subsurface (in-chip) structures. We observe modification size and length can be controlled by changing the beam profile and laser writing conditions. We show formation of 250 nm-thick in-chip structures, elongating >100 µm along laser propagation direction, reaching aspect ratios > 100 (**Fig. 1c-d**). Using different type beams and laser parameters, **we further create in-chip structures with features lower than 250 nm. To the best of our knowledge this constitutes the first controlled nanofabrication capability inside silicon**. These may be considered analogous to the broader approaches in nano-photonics [3].

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