DOI 10.5162/EUROSENSORS2025/M2.1.2

Development of Glass-Based Atomchip

Frederik Pöpsel[1], Alexander Kassner[1], Jannis Heinz[2], Hendrik Heine[3], Folke Dencker[1], Marc C. Wurz[1]
[1] Leibniz University Hannover, Institute for Micro Production Technology, An der Universität 2, 30823 Garbsen, Germany
[2] LPKF Laser & Electronics SE, Osteriede 7, 30827 Garbsen, Germany
[3] Leibniz University Hannover, Institute of Quantumoptics, Welfengarten 1, 30167 Hannover, Germany
Corresponding Author's e-mail address: poepsel@impt.uni-hannover.de

Summary:
In this work, we present the design and fabrication of a novel glass-based atom chip optimized for quantum applications. Atomchips are key components in quantum optics and technology, as they enable the control and manipulation of ultracold atoms on microscopic scales. Traditionally, atom chips have been based on aluminum nitride or silicon substrates; however, glass-based substrates offer significant advantages in terms of faster fabrication, optical transparency and electrical insulation.

Keywords: atomchip, glass-substrate, quantum technology, Laser-induced deep etching, quantum sensing

Introduction

The development of compact and efficient atom chips is becoming increasingly important for a wide range of applications in the fields of quantum measurement, atomic interferometry and quantum information processing. These chips use microscale conductor tracks on substrate materials to create magnetic micro traps for ultracold atoms [1]. Silicon substrates are commonly used for conventional atom chips [2]. During fabrication, these chips undergo a series of multi-step micro-engineering fabrication processes [3]. A significant disadvantage of using silicon as a substrate material is its opacity to the wavelengths used by the lasers. The use of glass as a transparent substrate offers completely new design possibilities. One notable advantage is the ability to introduce laser beams from the back of the chip. Furthermore, glass is an electrical insulator at the targeted temperature ranges. This has two advantages: First, it suppresses eddy currents that could otherwise affect chip functionality, and second, it eliminates the need for additional, potentially defect-prone insulation layers. These properties make glass an attractive substrate material for advanced atom chips. An additional advantage arises from the use of laser-induced-deep-etching process (LIDE). These can significantly reduce the total number of process steps, resulting in faster and potentially more cost-effective production [4]. Therefore, the development and production of a process chain for the production of a glass-based atom chips is investigated.

Methods

In the present work, a 500 µm thick BF33-wafer is structured using the LIDE process. This process enables the three-dimensional structuring of glass components without the use of masks, making it an extremely flexible tool for microstructuring. A flat surface is required for interferometry, which is why the cavities for the conductor tracks are embedded in the glass using LIDE.

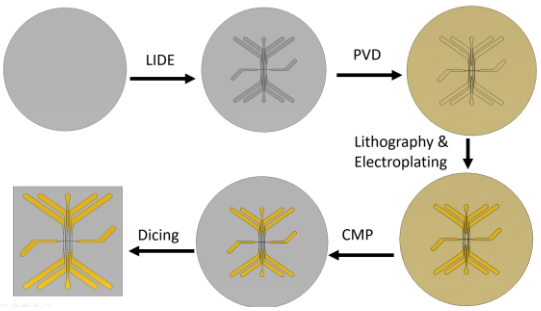

Fig. 1. Process plan of the glass-based atomchip

The LIDE process is divided into two steps. First, the glass is modified using a pulsed laser in a high-speed direct writing process. In this step, the glass structure is locally modified to increase the selectivity in the subsequent etching process. In the second step, wet chemical etching is carried out with a hydrofluoric acid (HF)-based solution. It can be seen that the areas previously modified by the laser are etched at a higher rate than the unmodified areas. This selective etching process enables the precise implementation of cavities that act as receptacles for conductor tracks. After structuring the glass wafer, a seed layer for electroplating is applied by physical

vapour deposition (PVD). First, a sputter etch step is performed to achieve a clean surface pre-treatment. Then, a titanium (Ti) adhesion promoter is applied, followed by a copper (Cu) layer as a seed layer. These layers serve to prepare the electrolytic deposition in the subsequent process. A photoresist is homogeneously applied to the substrate using a spin-coating process. This is then structured and developed using photolithography to expose the desired conductor track geometries. The previously created cavities are then filled by copper electroplating. This step ensures excellent electrical conductivity of the structures introduced. To ensure a flat and smooth chip surface, planarization by chemical-mechanical polishing is carried out in the penultimate step. Finally, the chip is diced into its final shape. The complete process (see figure 1) demonstrates an efficient and precise method for fabricating micro-structured glass components for use in microelectronics.

Results

The cavities after the LIDE process are shown in Figure 2. By optimizing the parameters such as pitch and etching time, the average roughness depth (R_z) and the arithmetic mean roughness (R_a) of the cavities for the conductor tracks could be reduced to a range that allows electrical applications (see table 1).

Tab. 1: Roughness values cavities

parameter	standard	optimized
Ra [µm]	0.65 ± 0.01	0.16 ± 0.02
Rz [µm]	3.25 ± 0.13	1.19 ± 0.25

The conductive tracks have been planarized after galvanic filling by using CMP. They have a depth of 14 µm. A greater depth would favor delamination of the conductor tracks during operation due to the layer stresses. After passing through the process plan, the diced atom chip (see figure 3) has a size of 30 x 30 mm and can be used for further experiments.

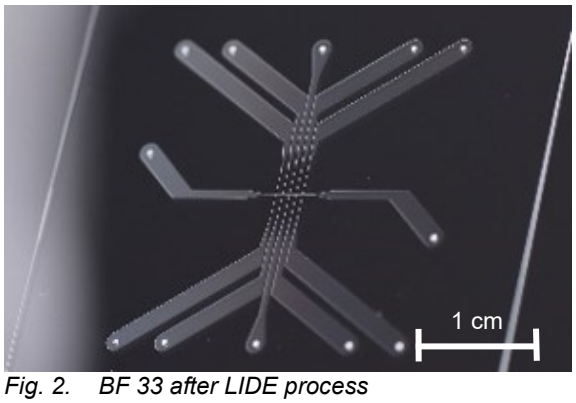

Fig. 2. BF 33 after LIDE process

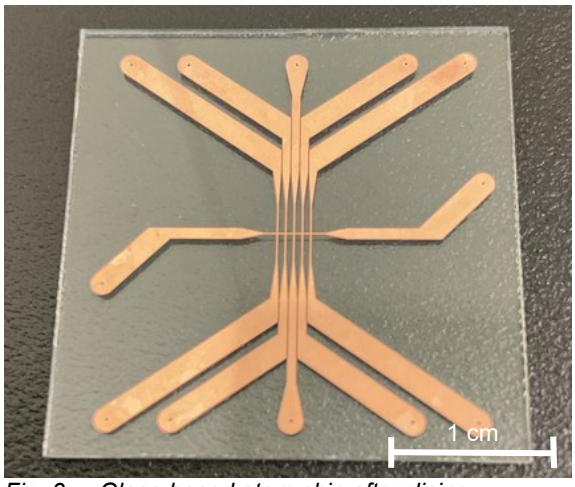

Fig. 3. Glass-based atom chip after dicing

Conclusion

By utilizing established manufacturing methods, we were able to develop a process plan for the production of a novel glass-based atom chip. Compared to the silicon-based standard, it can be produced faster and does not require any isolation layers, which are often prone to defects. In initial tests at atmospheric pressure, the lower thermal conductivity does not show any significant disadvantage. However, tests under vacuum are required and planned here.

References

[1] Keil, M. et al., Fifteen years of cold matter on the atom chip: promise, realizations, and prospects. *Journal of Modern Optics*, *63*(18), 1840–1885 (2016). https://doi.org/10.1080/09500340.2016.1178820

[2] Vivek Singh, V. B. et al., Development and characterization of atom chip for magnetic trapping of atoms. *J. Appl. Phys.* 28 February 2023; 133 (8): 084402. https://doi.org/10.1063/5.0130749

[3] A. Kassner et al., Atom Chip technology for use under UHV conditions, *Smart Systems Integration; 13th International Conference and Exhibition on Integration Issues of Miniaturized Systems*, Barcelona, Spain, 2019, pp. 1-7.

[4] R. Santos et al., Processing Glass Substrate for Advanced Packaging using Laser Induced Deep Etching, *2020 IEEE 70th Electronic Components and Technology Conference (ECTC)*, Orlando, FL, USA, 2020, pp. 1922-1927, doi: 10.1109/ECTC32862.2020.00300

Acknowledgements

This work has been carried out as a part of the joint project “Quantum Gravimeter with advanced LIDE-based Atomchip” (Q-GALA, funding code 03ZU1209KB) funded by the German Federal Ministry of Education and Research (BMBF) as part of the funding program QVLS-iLabs.