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Evaluation of resistless Ga^+ beam lithography for UV-NIL stamp fabrication

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Motivation

- UV-NIL is an established technique for high resolution pattern transfer [1]
- **Established template fabrication:**
  - Process involving E-beam lithography [2]
  - Process based on direct milling using Focused Ion Beam (FIB) [3, 4, 5]
- **Alternative fabrication approach:**
  - Implantation of Ga ions using FIB
  - Ga-rich layer serves as etch mask for dry etching of quartz [6]
  - Less writing time compared to direct milling
  - No resist needed (no need for coating, developing, etc.)

Experimental

- Conductive surface layer on quartz samples to avoid charging, carbon (~ 10 nm)
- **Ga Implantation**
  - FEI Helios Nanolab 600
  - Beam energy 30 keV
  - Doses from $1*10^{15}$ to $7.2*10^{17}$ cm^{-2}
- **Reactive Ion Etching (RIE)**
  - STS Multiplex ICP reactor
  - Etching gases C_4F_8 and O_2
  - Established etching process as starting point (optimized for Cr etch mask)
  - 28 sccm C_4F_8, 15 sccm O_2
  - 31 W bias power

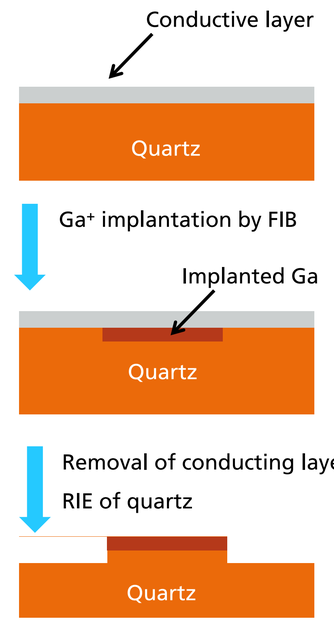

Fig. 1

Process scheme of template fabrication using resistless Ga+ beam lithography

Results and Discussion

- **Dose Dependency**
  - "Ga etch mask" not fully stable for low doses

  → High surface roughness after RIE
  - Once mask is stable, only small height variations after RIE

  → Major drawback for simple 3D structuring

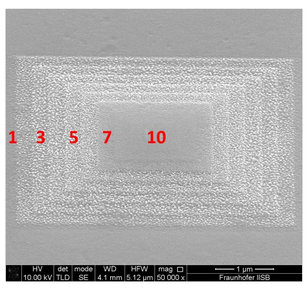

Fig. 2

Scanning Electron Microscopy (SEM) image of step pyramid, 10 steps (see red numbers) with 10 different implantation doses: $3.8*10^{15}$ – $3.8*10^{16}$ cm^{-2}

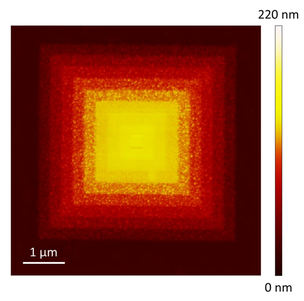

Fig. 3

AFM topography image of same step pyramid as shown in Fig. 2, Max. R_q: 7.54 nm (Step 3, see Fig. 2), Min. R_q: 0.45 nm (Step 10, see Fig. 2)

- **Optimization of dry etching process**
  - Significant rounding of structures during RIE (see Fig. 4)
  - Possibly due to enhanced sputtering at edges
  - Increase of C_4F_8 gas flow (28 → 88 sccm) to enhance polymer protection
  - Decrease of bias power (31 → 25 W) to reduce physical sputtering

  → Rounding reduced, anisotropic etching enhanced (see Fig. 5)

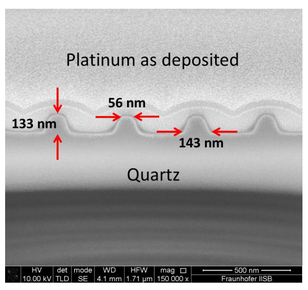

Fig. 4

Line pattern, implantation dose $3.6*10^{16}$ cm^{-2}, etched with established quartz etching process, process time: 2.5 minutes

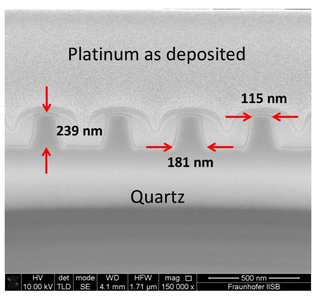

Fig. 5

Line pattern, implantation dose $3.6*10^{16}$ cm^{-2}, etched with optimized etching process, process time: 4 minutes

- **Imprint results**
  - Anti sticking layer (FDTS) applied via Molecular Vapor Deposition (MVD)
  - Successful replication of nanometer structures into UV-curing resist (mr-UVCur06, microresist technology)

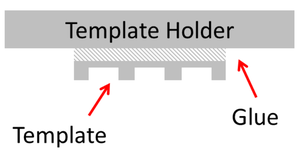

Fig. 6

Schematic view of fabricated quartz template glued to template holder using UV transparent hotmelt adhesive

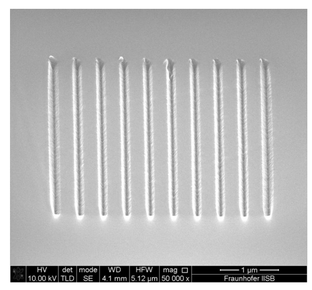

Fig. 7

SEM image of line pattern imprinted into mr-UVCur06, using a stamp fabricated by resistless Ga^+ beam lithography

Summary

- UV-NIL stamps were fabricated using resistless Ga^+ beam lithography
- Sufficiently high implantation doses result in very smooth surfaces after RIE (R_q < 1 nm)
- RIE process optimized for use of "Ga etch mask"
- Successful replication of nanometer structures

Outlook

- Quantified experiments concerning determination of selectivity between implanted areas and pure quartz
- Further optimization of dry etching process (anisotropic etching, etch rate, etc.)
- Determination of achievable maximum resolution and minimal pitch
- Optimization of imprint process

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