Thermal phase shifters for femtosecond laser written photonic integrated circuits

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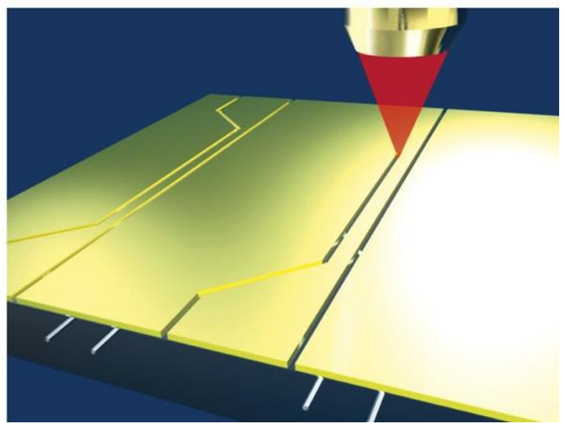
Compared to bulk and fiber optic systems, photonic integrated circuits (PICs) offer improved performance in terms of scalability, compactness and stability at a lower cost. Femtosecond laser micromachining (FLM) is a promising technology for the rapid and cost-effective manufacturing of PICs. Reconfigurability in FLM circuits can be achieved with thermal phase shifters (i.e. resistive microheaters), fabricated by depositing a gold film on top of the substrate and ablating it with a femtosecond laser. Here, we exploit this technology to demonstrate a 6-mode universal photonic processor featuring 30 thermal shifters isolated by 60 deep trenches. However, this kind of thermal shifters is severely limited in terms of integration density and, for this reason, we are currently investigating a lithographic fabrication process in PoliFAB. Being spin coating of liquid photoresist not easily compatible with deep isolation trenches, we are now developing a new fabrication process based on dry film photoresist lithography to overcome the limits of gold-based thermal shifters while retaining the advantages of thermal isolation.

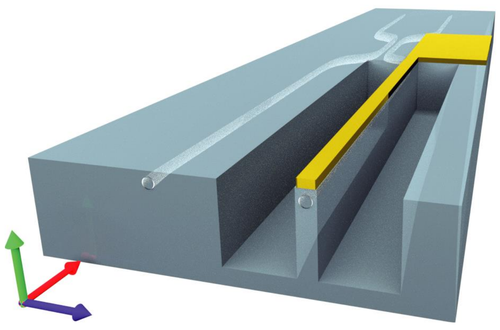
Gold thermal phase shifters via FLM



> FABRICATION PROCESS

- Thermal evaporation of gold film
- Thermal annealing
- FLM ablation of resistors

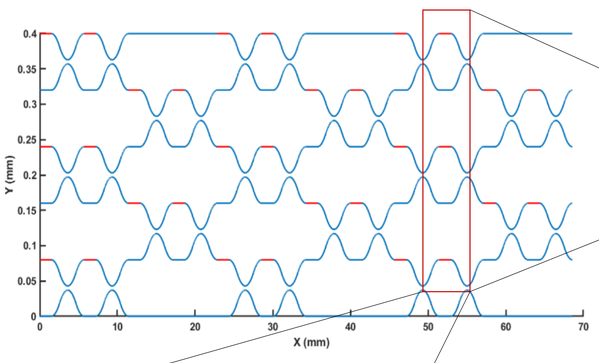
Thermal annealing at 420°C ensures improved stability and reliability

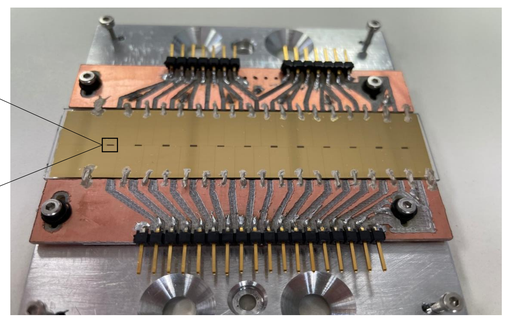


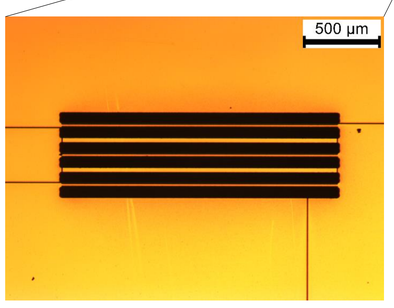
> THERMAL ISOLATION

Thermal isolation structures such as **deep trenches** significantly reduce power dissipation and thermal crosstalk

> 6 MODE UNIVERSAL PHOTONIC PROCESSOR



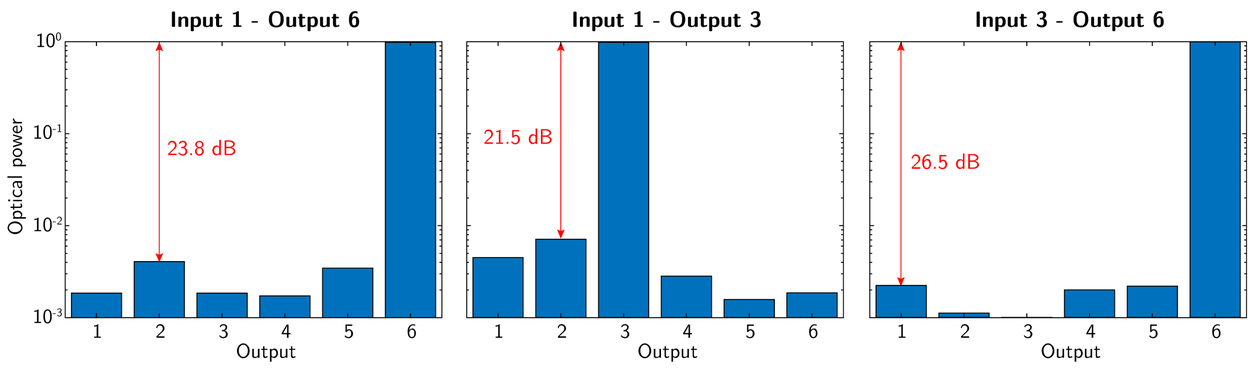




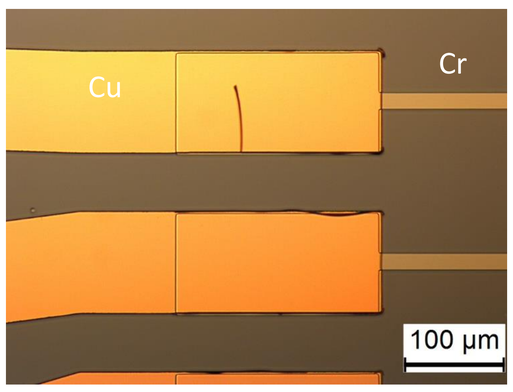
30 microheaters featuring deep isolation trenches on the same 9 cm long device

Upper limit for integration of gold thermal shifters

> FIRST APPLICATION: PHOTONIC SWITCHING



Lithographic thermal phase shifters

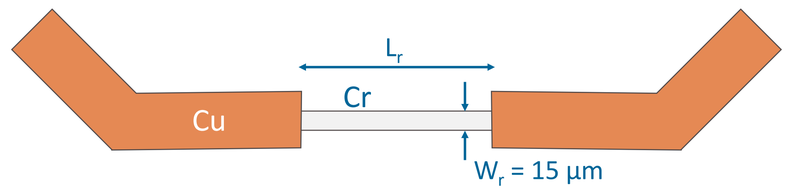


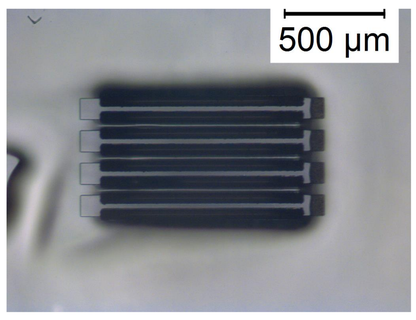
> DESIGN

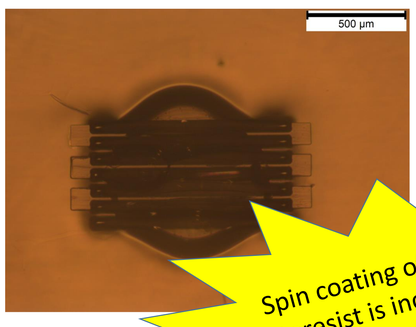
Chromium resistor:
- good adhesion to glass
- good thermal stability

Copper interconnections:
- wire-bonding compatible
- low resistivity

Chromium and copper are deposited by **E-beam evaporation** in two separate lift-off lithography steps.



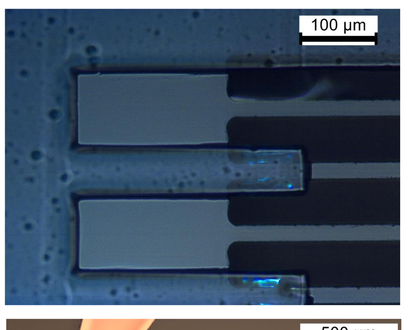


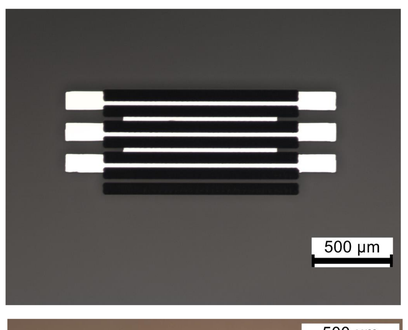


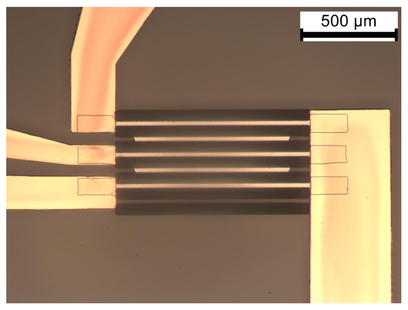
Spin coating of liquid photoresist is incompatible with deep trenches

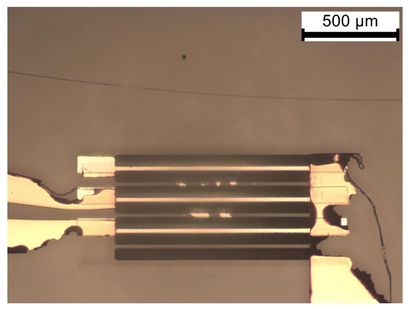
> DRY FILM PHOTORESIST

Coating by lamination of thick negative Ordyl FP450 resist









Second lift-off of thick copper presents some tearing issues limiting yield. Optimization in progress…

References

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[3] Ceccarelli et al. *Laser & Photonics Reviews* **14**(10), 2000024 (2020).
[4] Pentangelo et al. *Physical Review Research* **3**(2), 023094 (2021).

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