Dynamic Photo-Robotic Nanopositioning for Hybrid Photonic Circuits Based-on Self-Sensing tuning Fork

Morris Mwangi[1,2], Mokrane Boudaoud[3], Jean Byiringiro[2], Philippe Lutz[1], Nadège Courjal[1] and Cédric Clévy[1]

[1]FEMTO-ST institute, Université de Bourgogne-Franche-Comté, 25000 Besançon, France
[2]Dedan Kimathi University of Technology, 10100 Nyeri, Kenya
[3]Intelligent Systems and Robotics Institute, 75005 Paris, France

morris.mwangi@femto-st.fr , Mokrane.boudaoud@isir.upmc.fr, jean.bosco@dkut.ac.ke, philippe.lutz@femto-st.fr, nadege.courjal@femto-st.fr & cedric.clevy@femto-st.fr

Abstract

Interaction forces between objects become dominant while working at the micro and nano scales and thus cannot be overlooked in the assembly of micro and nano sized elements. Particularly, in the case of photonic components, owing to their delicate nature, there is a need to develop assembly methods that will ensure enough positioning accuracy and safety while preserving the physical property of the elements. It is the key to ensure the optimal working assembled photonic device. Here we propose a new approach for the safe and accurate assembly of photonic elements relying on a self-sensing tunin fork based AFM able to detect attractive and repulsive interaction forces. The originality of the method relies on the detection of small scale non-contact interaction forces providing key information on the relative distance between photonic components. For the case of example, we use an optical micro-resonator disc and a membrane based electro-optic modulator whose interaction generates an optical resonance whose quality factor depends on the quality of the individual elements and the separation distance between them which needs to be controlled within 100 nm accuracy.

1. Introduction

While photonics is emerging as an attractive alternative to electronics in high bit rate telecommunication systems, sensors or signal processing devices, there is a strong need of specific 3D hybrid photonic architectures that cannot be easily engineered by clean-room processes, such as miniature integrated electro-optic polarization modulators or photonic crystals in non-standard electro-optic materials [1]. The specifications of these photonic elements are highly dependent on their geometrical parameters and the relative positioning of these components with respect to one another. The fragility of these component is a key issue that determines the yield factor of any set of assembled components. The low yield factor in the assembly of hybrid elements have been linked to the their fabrication process in literature [1]. However, it is noteworthy that the assembly process uncertainties, that are determined by the nature of interaction of the elements at small scale, during the process has a major contribution to the success of a given assembly. The current assembly processes for 3D photonic circuits in literature have shown great potential in the development of hybrid structures and various assembly methods have been proposed. Examples include: Wafer bonding, transfer printing, pick and place [2]. Previous work on robotic positioning of photonic elements have shown high positioning accuracies of 50 nm and 0.004° in positioning and orientation respectively [3]. However, there is need to develop a method that takes into account the interaction forces to enable high efficiency in assembly.

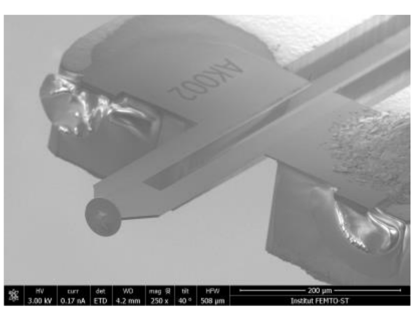

Figure 1: Micro resonator assembled on Akiyama probe by tele-operation under FIB

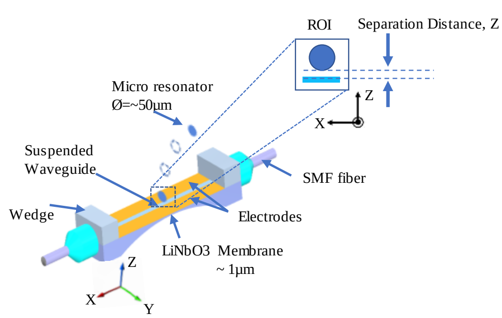

Figure 2: Scheme of the proposed waveguide-resonator assembly

In this work, we propose dynamic photo-robotic nanopositioning of photonic elements that puts in consideration the unprecedented effects that could be caused by possible hard contact of elements during the assembly process. Notably the interaction forces which could either be repulsive and or attractive (van-der-Walls forces, Electrostatic forces) that become dominant when small scale devices are brought into close proximity [4]. This approach will help in pre-contact detection which will allow controlling the interaction forces between assembly elements and the precise control of the distance between the elements.

2. Dynamic photo-robotic nanoposition

The Atomic Force Microscope (AFM) technology has been used for characterization of nano elements and also for nano imaging purposes. Recent studies on the topic have proposed tip landing control strategies to ensure fast landing and prevent damage on delicate tip during in the process [5]. To be able to measure the interaction forces between the waveguide and the resonator, we propose use non-contact principle of the AFM to get a frequency shift, with an Akiyama probe that has a micro resonator pre-assembled under FIB as shown by Figure 1, which is proportional to the interaction force of the elements in contact or in close proximity. The scheme on Figure 2 shows the proposed waveguide resonator assembly. Preliminary characterization of the waveguide and the resonator has shown low insertion losses of 3.2 dB as shown by Figure 3 and high quality factor of 1.78×10^4 respectively. In order to guarantee optimum operation of the assembly, we use the non-contact principle where we anticipate a contact using the adhesion forces where the net interaction between the resonator and the waveguide is negative. The experimental result of approach-retract curve with the region of interest is shown in Figure 4. We are currently developing a hybrid control strategy that will allow closed loop control of the distance betweem the elements using the frequency shift feedback and the optical signal that will limit the interaction between them and also ensure the optical functionality of the assembly.

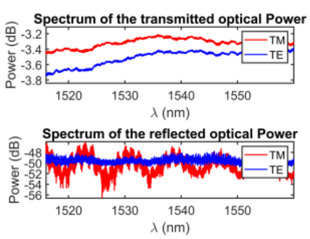

Figure 3: Transmission and reflexion spectra of the low loss waveguide (~3.2 dB)

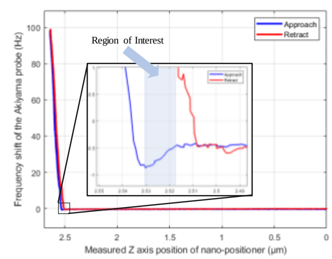

Figure 4: Approach Retract curve of an Akiyama probe approaching a sample surface

3. Conclusion and Discussions

We have presented an original photo-robotic approach for the high accuracy nano positioning of photonic elements relying on interaction forces between them. The proposed method will ensure controlled contact between the elements thus high yield factor and high quality for the assembly due to reduced damages on the components. This is a promising approach towards development of assembled 3D nano-photonic architectures such as miniaturized integrated micro-resonators and polarization rotators.

Acknowledgement

These works have been partially funded by the Bourgogne Franche-Comté région and the COLAMIR project (contract “ANR-16-CE10-0009”), supported by the EIPHI Graduate school (contract "ANR-17-EURE-0002"), Robotex contract "ANR-10-EQPX-44-01" and the French RENATECH network through its FEMTO-ST technological facility.

References

1. F. Najafi *et al.* (2015). On-chip detection of non-classical light by scalable integration of single-photon detectors,” *Nat. Commun.*, vol. 6
2. Elshaari A. W. et al. (2020). Hybrid integrated quantum photonic circuits. *Nat. Photonics*, vol. 14, no. May, pp. 285–298
3. H. Bettahar et al. (2020). 6-DoF Full Robotic Calibration based-on 1-D Interferometric Measurements for Micro and Nano-Scales Applications,” *IEEE Trans. Autom. Sci. Eng*
4. Zhang J. and Zeng H. (2021) “Intermolecular and Surface Interactions in Engineering Processes,” *Engineering*, vol. 7, no. 1, pp. 63–83
5. J. Cailliez et al. (2020). Robust Hybrid Control of an Atomic Force Microscope for Characterization of interaction Force Region at Nanoscale,” *IEEE Trans. Control Syst. Technol.*, vol. 29, no. 4, pp. 1689–1703