Flip-chip assembly of an integrated optical sensor

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For enabling low cost mass production for photonic circuits, the application of flip-chip technology creates huge expectations. We report on the results of a project, having the goal to demonstrate standard packaging technology in combination with integrated optics, entailing demands and limitations different from IC technology. Mainly fiber attachment, but also special features as sensor window accessibility at the top-side of the chip are prohibiting the positioning of the optical layer stack and solder pads at the same side of the silicon wafer. Therefore, feed through technology had to be included. Compatibility issues in combining feed through technology with integrated optics processing have been solved and the feasibility of feed-through metallization and flip-chip assembly in combination with an integrated optical sensor has been demonstrated.

Introduction

Separation of the electrical contacts and the active area of integrated optical devices would enable the application of more conventional IC assembly and packaging technologies, reducing costs and increasing reliability. The goal of this project was to combine integrated optics technology with feed-through technology, to create electrical contacts on the backside of the chip. The combination of these technologies will enable easy assembly applying flip-chip technology. Furthermore, the size of available chip area for functional devices on the frontside of the chip will be increased, what is especially of interest for multi-channel devices. In the specific case of integrated optical sensors, operating in the chemical domain, transfer of the electrical wiring towards the backside of the chip is particularly interesting because it increases the de-coupling of the electrical contacts and the environment and also allows for an improved hermetic packaging.
In this paper, we describe the development of a flip-chip enabled assembly technology for a multi-species integrated optical sensor.

Technology: State of the art

The sensor device of interest is the integrated optical (IO) version of a very sensitive measuring principle, the Mach-Zehnder interferometer (MZI). The layout of the MZI sensor [1] is schematically shown in Figure *1* (a, b). The feed-through technology [2] for electrical interconnects from the wafer front towards the wafer backside, as developed by Hymite, is depicted in Figure *1* (c). This technology is based on plating of the metallization layer and lithography into the feed-through hole applying Eagle resist. Flip-chip bonding (Figure *1* d), is established by placing solder balls on the metallization pads of the optical chip and soldering carrier (with metallization) to chip at elevated temperature. The aim of this project was to solve integration issues when joining both technologies and to demonstrate the operation of flip-chip bonded sensors.

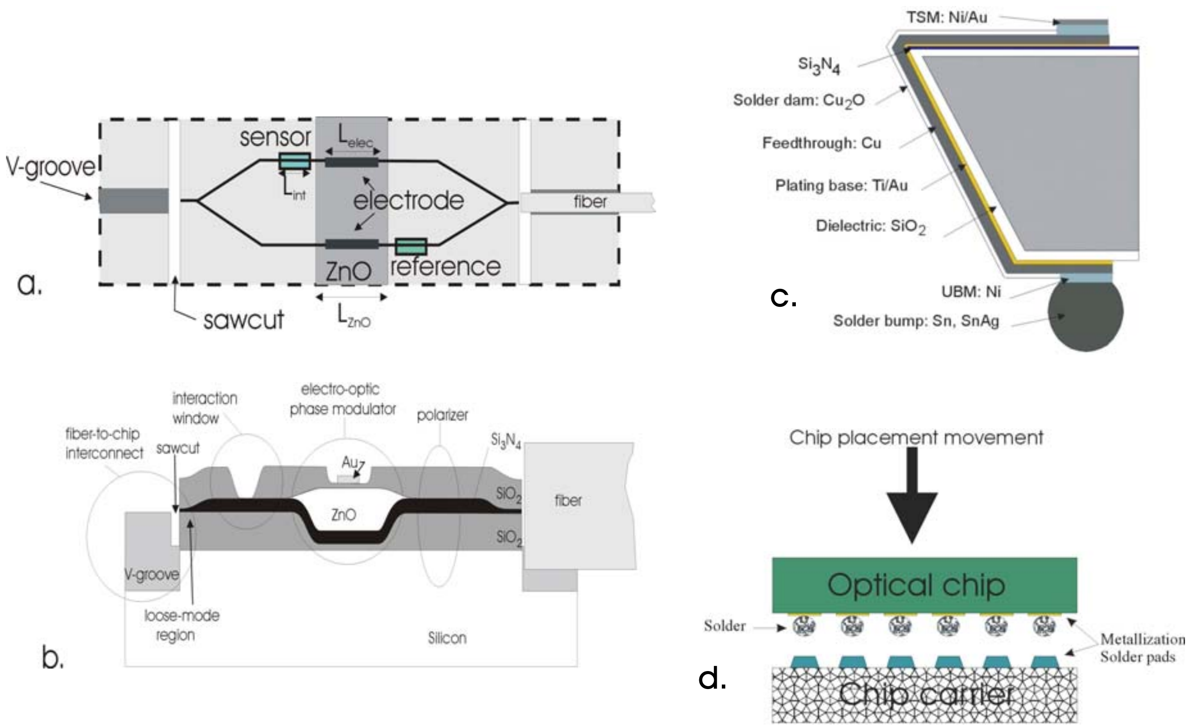

Figure 1: Top view (a) and cross-section (b) of the integrated optical MZI configuration [1], metallization stack layout [2] (c) and flip chip principle for optical chips on carriers (d)

Technology integration and Design

Chip layout: In order to realize a device allowing for multi-species sensing (5 channels), the design of the original MZI sensor has been adapted to a multi-channel layout. The design resulted in 40 mm long and 4 mm wide chips each containing 5 MZI channels and 2 feed through sections. Metallization layout for the front and backside of the chips has been developed.

Metallization choice: For the MZI operation, highly conducting metallization (without voltage loss) is required. Gold in combination with a Cr adhesion layer has been chosen. The metallization lines had to be at least 200 nm thick and between 50-100 µm wide with a resolution of ± 10 µm. This demand seemed to be compatible with the features of the feed-through metallization. Therefore, it was possible to use the feed-through metallization also for the definition of the front-side electrodes, yielding reduced cost in production.

Chip carrier choice: The requirements relevant for a ceramic chip carrier applied in the assembly of the optical MZI chip are mainly based on thermal expansion match between carrier and chip, flatness of the available carrier material (< 10 µm, large chip size!) and good insulating properties of the carrier. Based on the demands in combination with the properties of the available carrier materials, Pyrex has been chosen.

Integration issues: When combining the above-described technologies for the fabrication of integrated optics devices and feed-troughs, several restrictions and requirements have to be taken into account. In this approach, it is of major importance that both technologies can be combined without disturbing the functionality of any device part. The most important technology integration issues that had to be solved for this approach are:

- Temperature budget vs. high temperature KOH protection layers
- KOH resistivity vs. lithographic accuracy
- Chip flatness vs. feed-through profile
- Soldering vs. sensor window pollution

Based on the short-loop results of the integration issues in combination with requirements from the assembly and packaging process, the flip chip enabled MZI sensor layout has been developed as depicted schematically in the cross-sectional view of *Figure 2*.

Figure 2: Schematic layout of MZI device with feed-through hole and metallization to be fabricated; sectional overview with 1-fiber-chip coupling section (longitudinal section), 2-sensing window section (cross-section), 3-modulator section (cross-section), 4- feed-through section (cross-section); all sections are schematic.

Results

The flip-chipped demonstrator device has been fabricated according to the established processing scheme, assembled packaged and tested. In Figure 3, a picture of the flip-chip bonded multi-channel sensor is shown, whereas sensor chip, Pyrex carrier and metallization layout can be clearly distinguished. In Figure 4, the fully assembled and packaged sensor, including the optical connector, is shown.

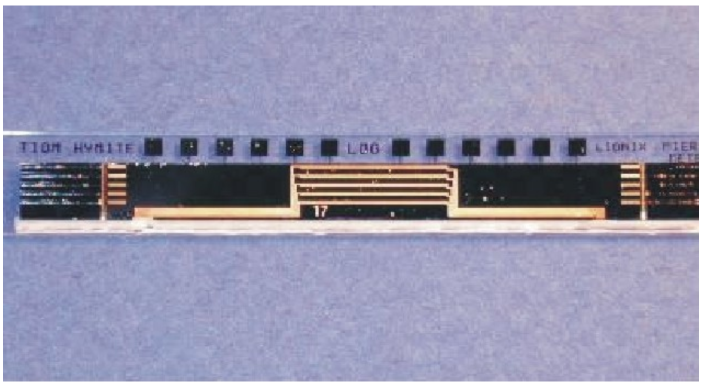

Figure 3: Photographs of the flip-chip bonded sensor chip

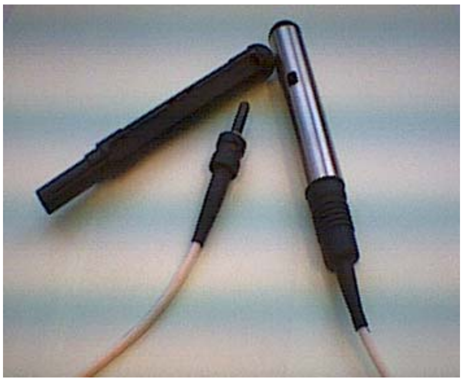

Figure 4: Photograph of the fully assembled and packaged sensor device

The response of an electro-optically modulated sensor device (with and without feed-through metallization) on relative humidity change is given in Figure 5. Based on this measurement we can conclude that the response of the sensor with the flip-chip enabled metallization scheme corresponds with the behavior of earlier fabricated sensors, which are operating based on the conventional metallization scheme.

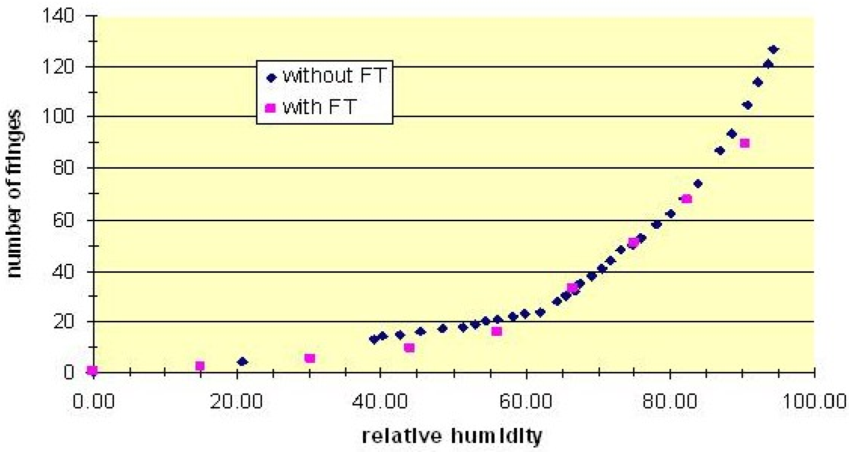

Figure 5: Measured response of the sensor device on relative humidity change.

Conclusion

We have successfully demonstrated the combination of integrated optics and feed-through technology enabling flip chip bonding of optical chips onto chip carriers provided with metallization. A fully packaged integrated optics sensor, fabricated by this combined technology, has been realized and measured. The response was found to be comparable with earlier fabricated sensor devices, on which the conventional metallization scheme had been applied.

Acknowledgements

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