Improving thermal performance of a UTC photodetector in the IMOS platform

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Recently a uni-traveling carrier photodetector (UTC-PD) with a 3 dB bandwidth beyond 67 GHz was presented [1]. The device shows good performance up to 3 mA of photocurrent but experiences thermal failure (see Fig. 1a) at higher currents due to the poor heat extraction in membrane-type devices. Improvements to the thermal design are proposed that promise to double the possible photocurrent before thermal failure, which makes the performance comparable with state-of-the-art SOI UTC-PDs [2].

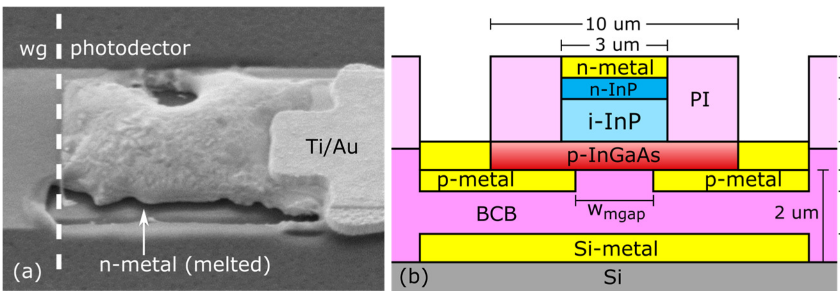

Fig. 1. SEM image (a) of the UTC-PD, the n-metal has melted due to high photocurrent. Schematic cross section (b) of the UTC-PD with the width of the p-metal opening (w_{mgap}) and the thickness of the BCB between the p-metal and Si-metal (h_{mgap}) indicated.

Extracting heat from the InP membrane is difficult as it is surrounded by air on top, and BCB below (see Fig. 1b). Currently the majority of the generated heat is extracted through the p-contacts as they have a large surface area compared to the device. Little heat is extracted through the silicon wafer due to the low thermal conductivity of BCB. The heat extraction through the p-metal can be improved by reducing w_{mgap}. This can be done without increasing the optical loss significantly if a solution like proposed in [3] is used to make low optical loss p-contacts. We can also improve heat extraction through the silicon wafer by replacing part of the BCB with metal, leaving a gap of h_{mgap} between the p-metal and Si-metal. The total thickness is kept the same so that changes to the processing are limited and the optical losses in passive waveguides can be kept low.

Commercial multiphysics simulation software is used to first find the fundamental optical mode in the device, which is used to determine the electron-hold pair generation for the semiconductor simulation. This gives the heat source term in the thermal simulation. Setting the photocurrent at 3 mA, the thermal conductivity to the surroundings is set so that the temperature at the n-metal alloy reaches its melting point of 360 °C. For different adjustments of the device the photocurrent is set again to reach the melting point.

In this way the maximum photocurrent before thermal failure is determined for different values of w_{mgap} and h_{mgap} (Fig. 2). Significant improvement can already be seen when w_{mgap} is reduced by only 500 nm. Introducing metal on top of the silicon also gives significant improvements, doubling the maximum current when the BCB gap is reduced to 10 nm. Choosing $w_{\mathrm{mgap}} = 2.5$ um, $h_{\mathrm{mgap}} = 10$ nm is expected to yield a maximum photocurrent of 7.5 mA. With a responsivity of 0.7 A/W, this leads to an UTC-PD with an optical input power of 10.3 dBm, which is comparable to state-of-the-art in SOI [2].

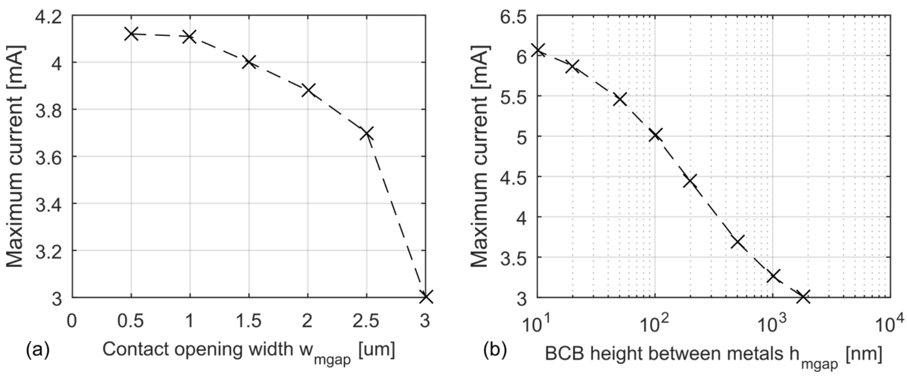

Fig. 2. The maximum current before reaching the temperature at which the top metal contact melts is shown as a function of a) the contact width opening w_{mgap} and b) the BCB height between the p-metal and the metal on top of the silicon.

Other improvements to obtain higher optical input power are 1) increasing responsivity by introducing an electron-block layer at the p-contact, and 2) introducing band-smoothing layers at the p-InGaAs / i-InP interface to operate the device at lower voltage.

We investigated improvements to the thermal design of a UTC-PD. Improving thermal conduction to the silicon wafer by means of a metal bridge doubles the maximum current before thermal failure. These ideas will be usable for other active membrane devices.

References

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[2] X. Xie et al, *High-Power and High-Speed Heterogeneously Integrated Waveguide-Coupled Photodiodes on Silicon-on-Insulator*, J. of Lightwave Technology, Vol. 34, No. 1, pp. 73-78, 2016

[3] L. Shen et al., *Ohmic contacts with ultra-low optical loss on heavily doped n-type InGaAs and InGaAsP for InP-based photonic membranes*, IEEE Photonics Journal, Vol. 8, No. 1, 2016