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## 29GHz-bandwidth monolithically integrated EAM-VCSEL

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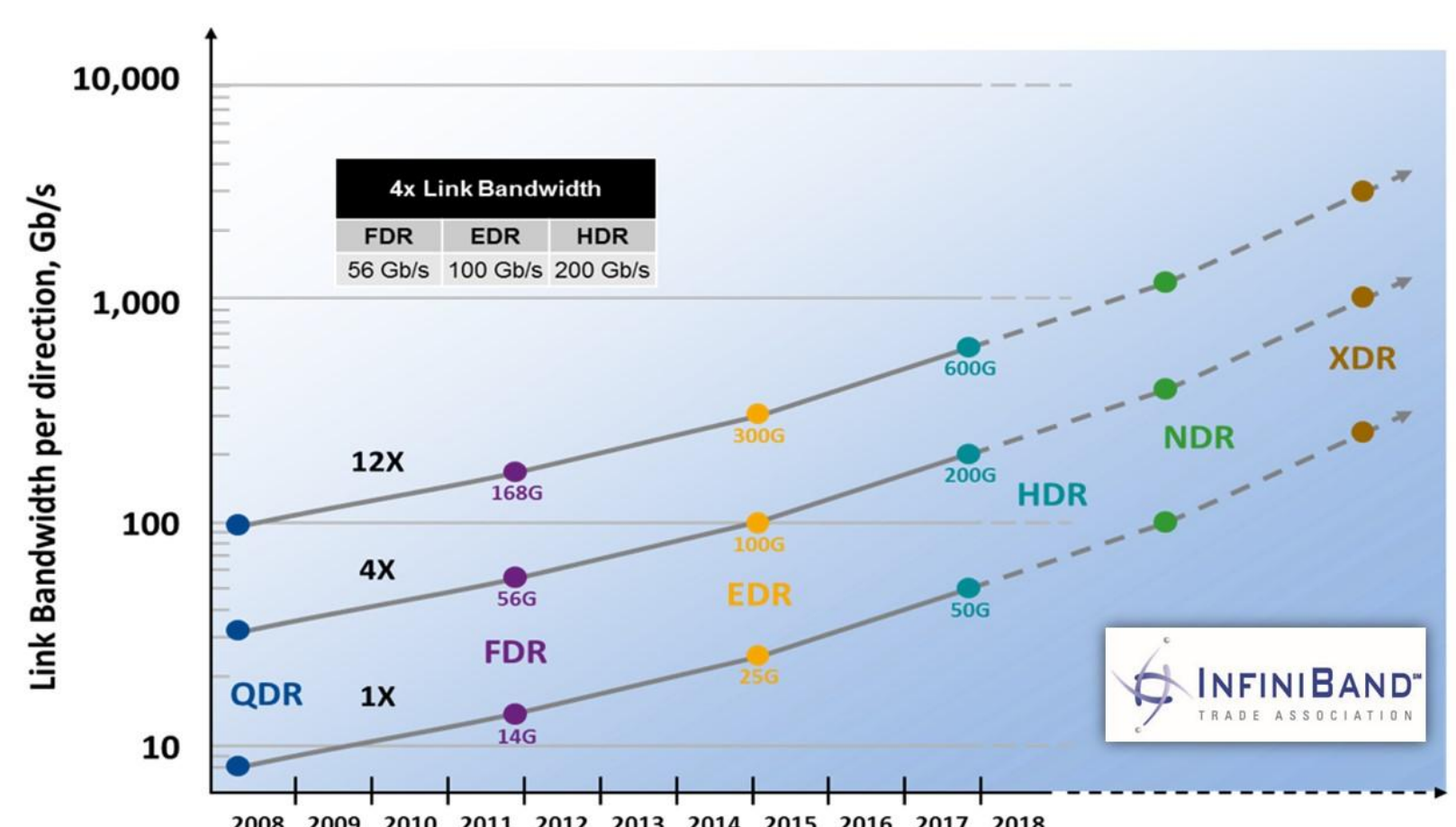
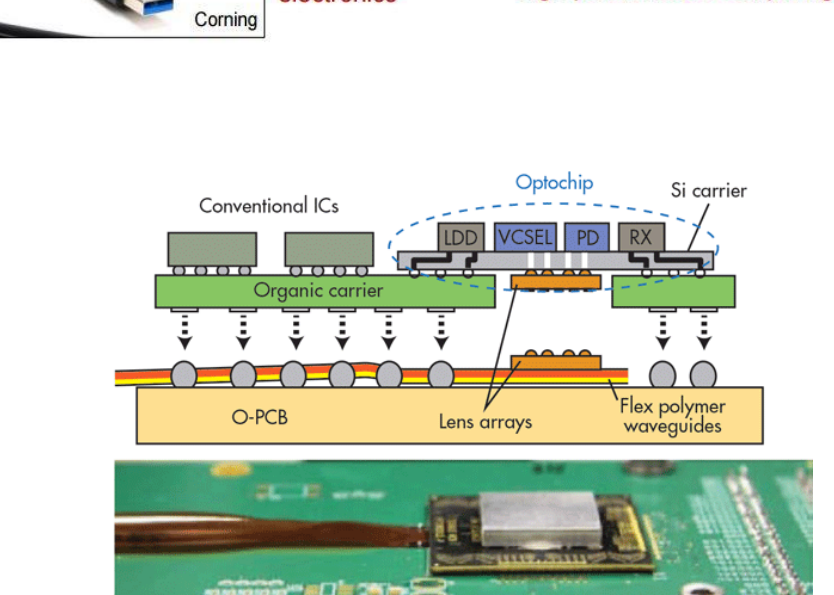
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## High-Speed modulation with VCSELS

### High speed VCSEL applications :

- Short-reach optical links in Datacenters
- Smartphones (3D imaging)
- Optical cables (USB, video)
- High performance computing
- Free space optical links
- System on Chip (SoC)

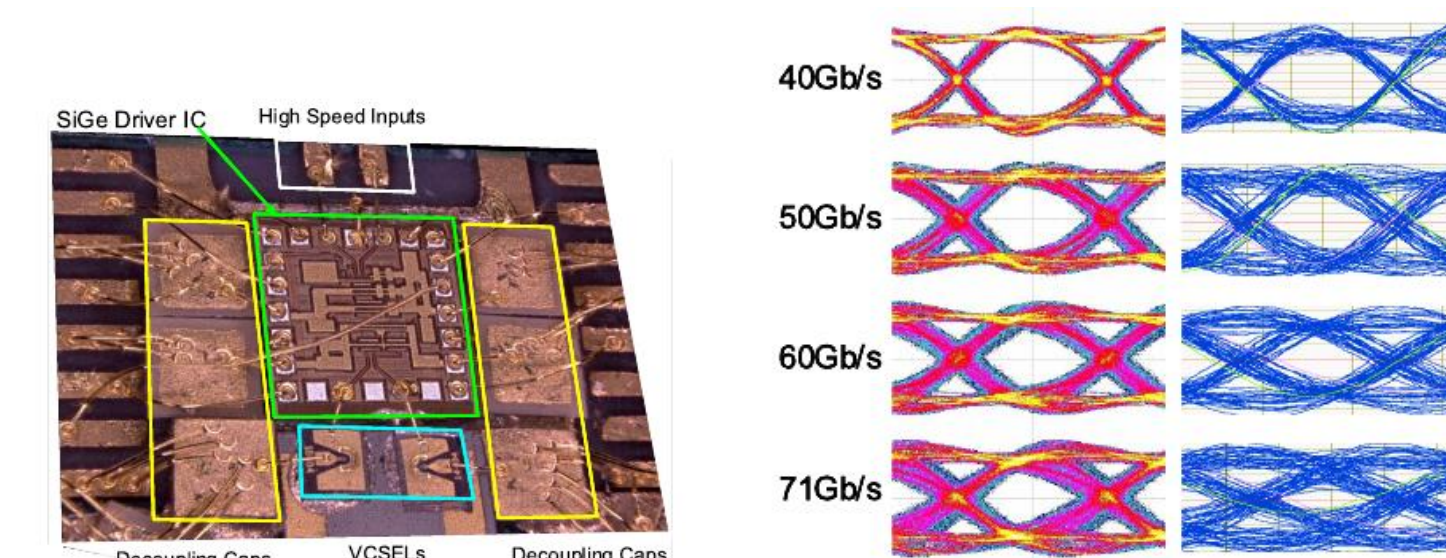


### State-of-the-art

71Gb/s VCSEL by Chalmers, IBM, 2015 (Kutcha et al., PTL, 2015)

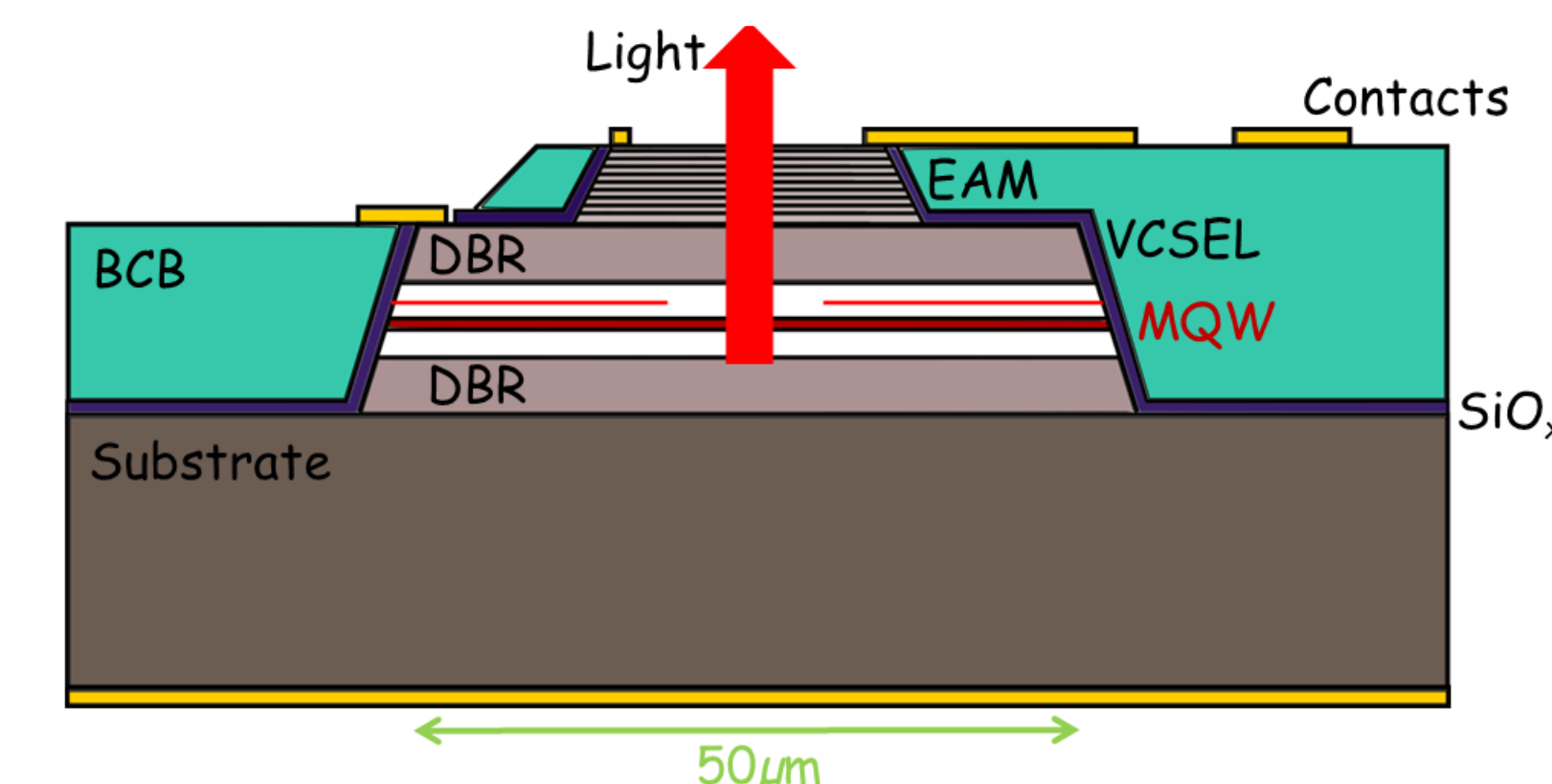
Others approaches to increase VCSEL bandwidth:

- T-VCSEL (KTH) (Akram et al., OE, 2014)
- Coupled-Cavity VCSEL (Dalir et al., APE, 2015)
- 6-VCSELS arrays (6x40 Gb/s ↔ 240 Gb/s) (Westbergh et al., PTL, 2015)
- Dual-cavity VCSEL (Van Eijsden et al., PTL, 2008)



### Our approach = Vertically Integrated Electro-Absorption Modulator on a VCSEL

- ⇒ Splitting up Emission / Modulation
- ⇒ High bandwidth
- ⇒ Electro-absorption modulator : high bandwidth
- ⇒ High devices density, small footprint
- ⇒ Not limited by carriers/laser dynamics

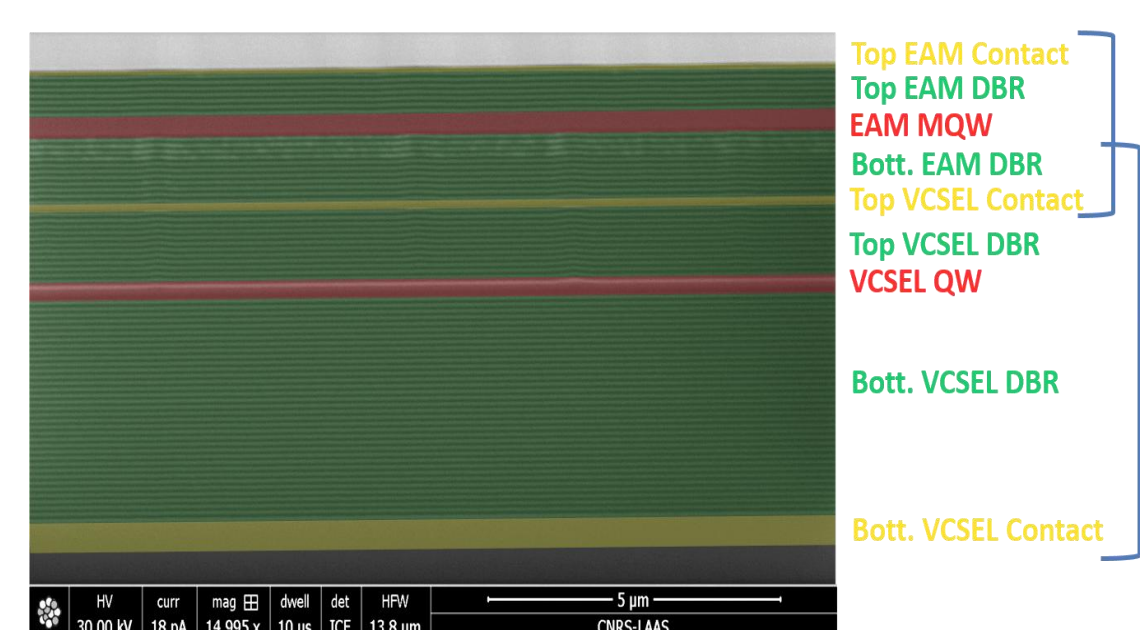


## Fabrication technology

### Original technological bricks developments :

#### - Molecular beam epitaxy :

Double microcavity stack, Digital alloyed QWs (EAM), Monitoring : reflectometry, optical flux monitoring (OFM), wafer curvature



#### - Self-aligned lithographic process flow :

etching / passivation / metallization

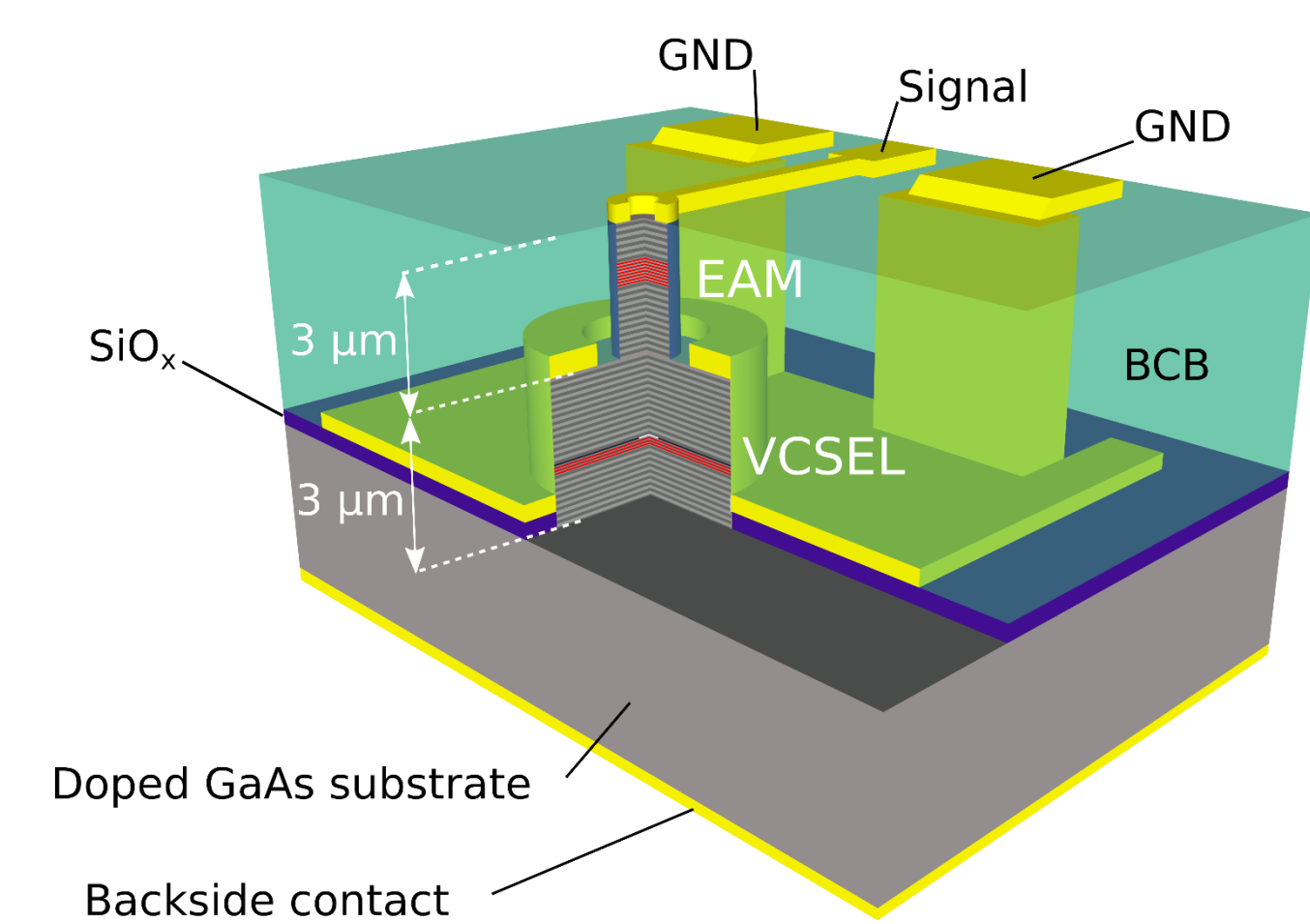
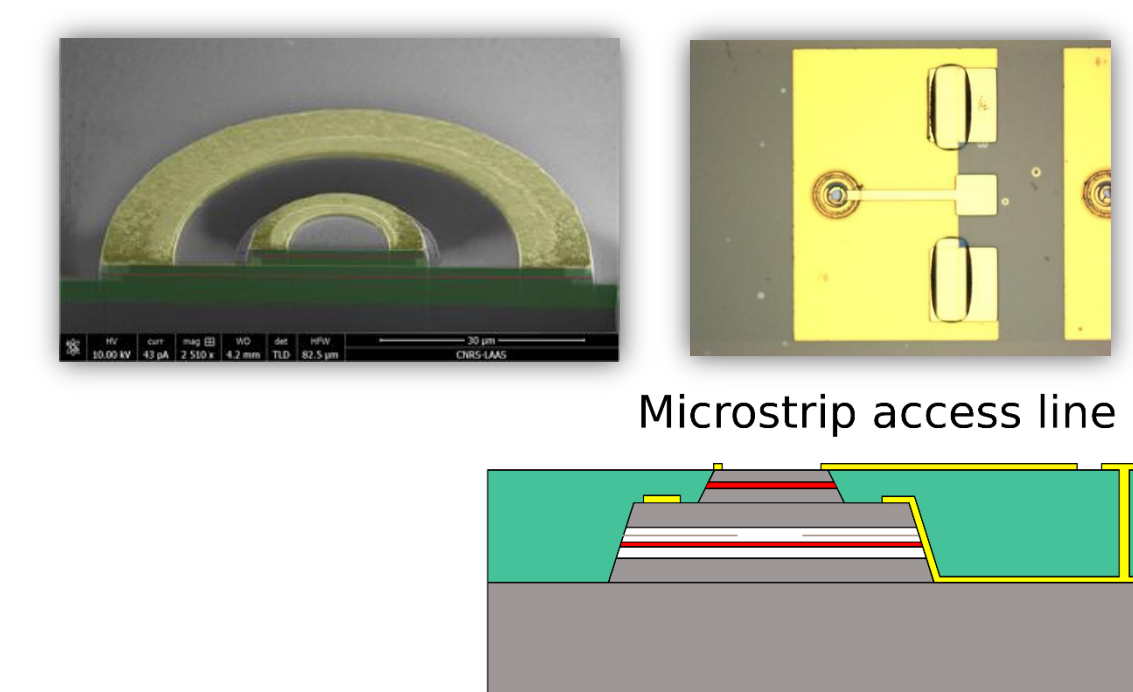
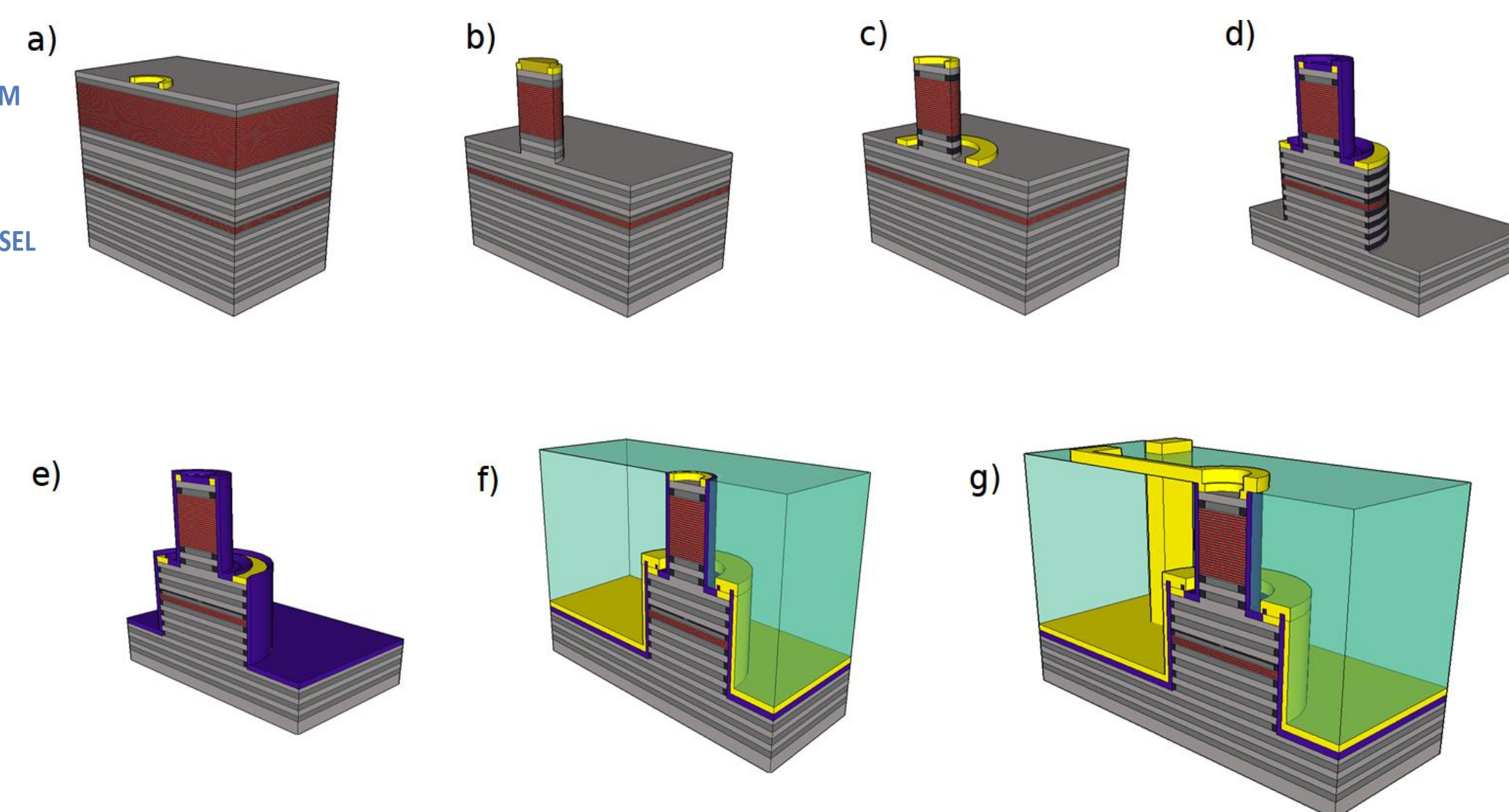
L. Marigo-Lombart et al., Mater. Sci. Semicond. Process. 61, 35 (2017)

#### - BCB planarization :

mechanical pressing step (nanoimprint) / ICP etching

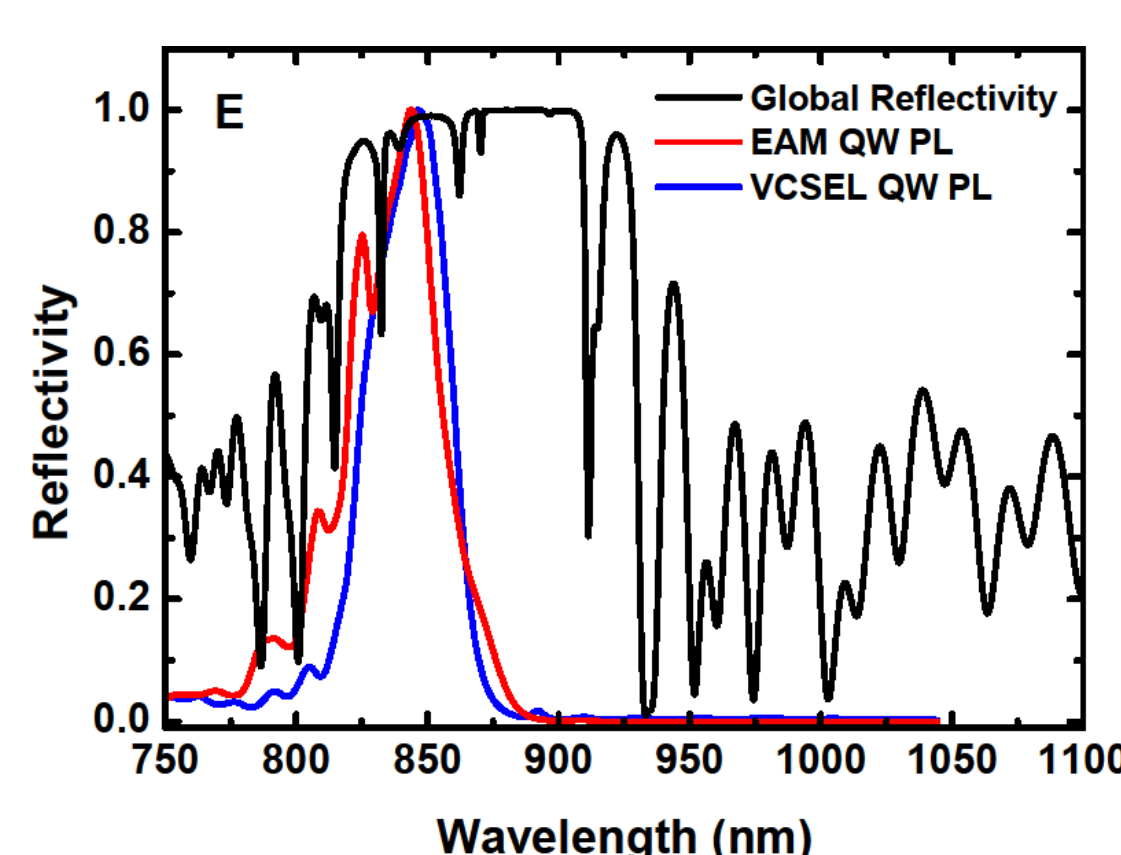
#### - RF design of the contact pads : Microstrip geometry

L. Marigo-Lombart et al., IEEE J. Lightwave Technol. (2019)

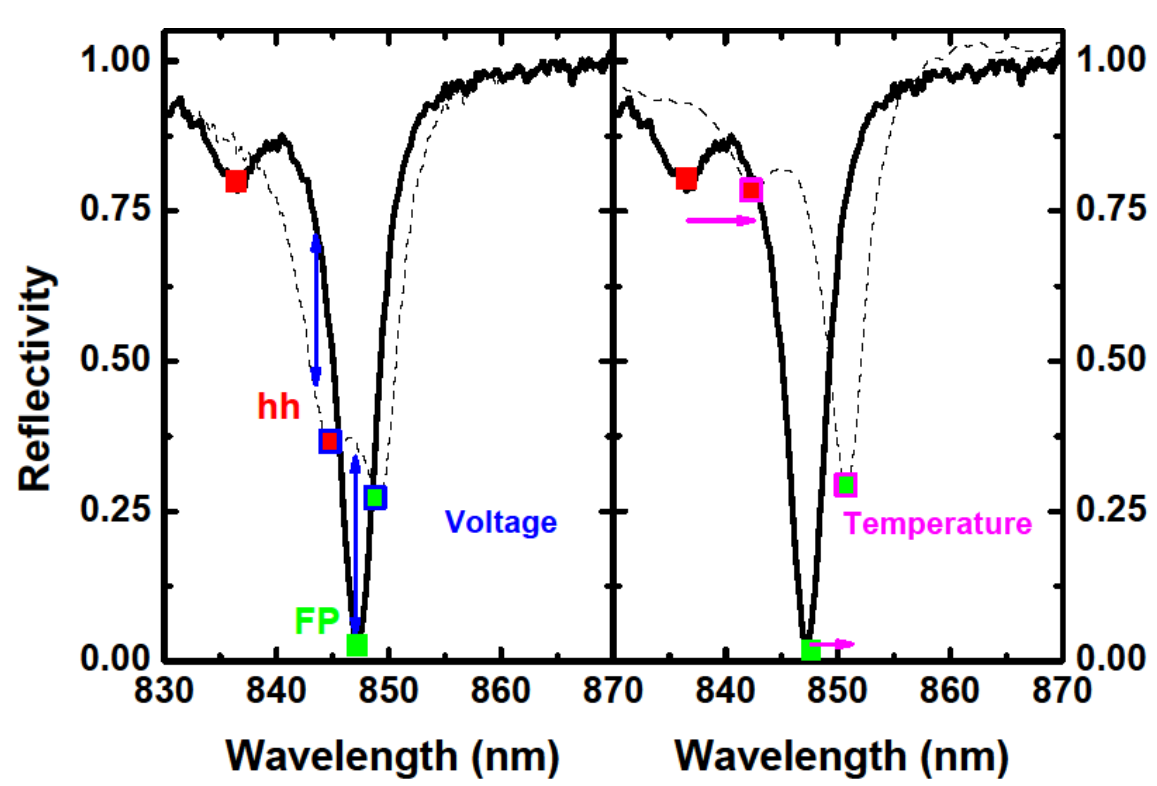


## EAM-VCSEL characterizations

### Static electro-optical characterizations

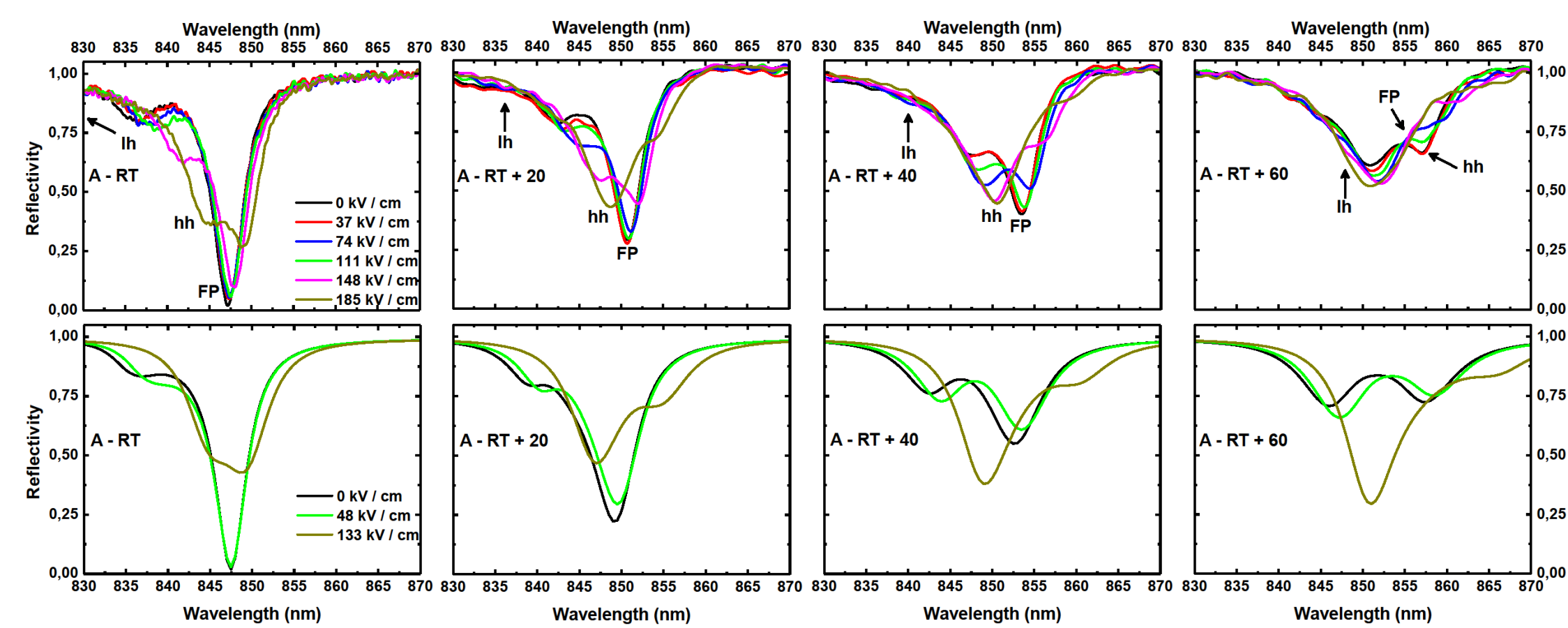


#### Wavelength detuning : Reflectivity / gain & absorber

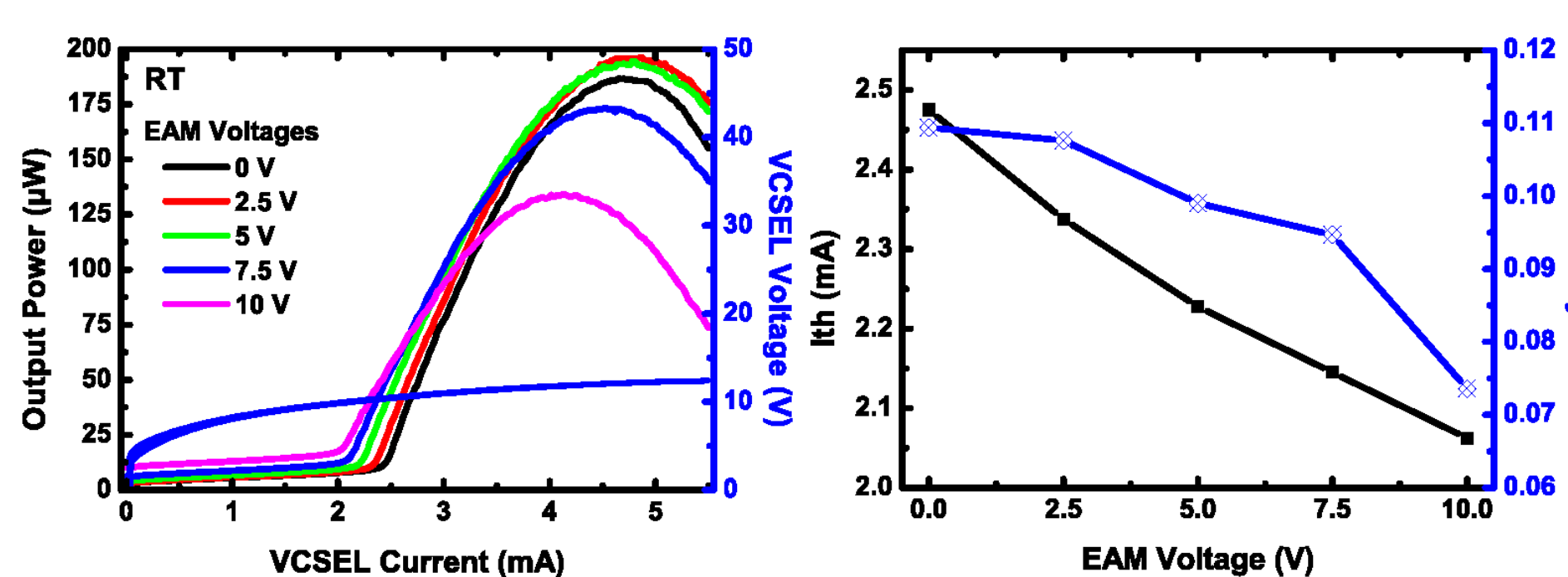


#### Influences of biased field / temperature

L. Marigo-Lombart et al., J. Phys. D: Appl. Phys. 51 145101 (2018)



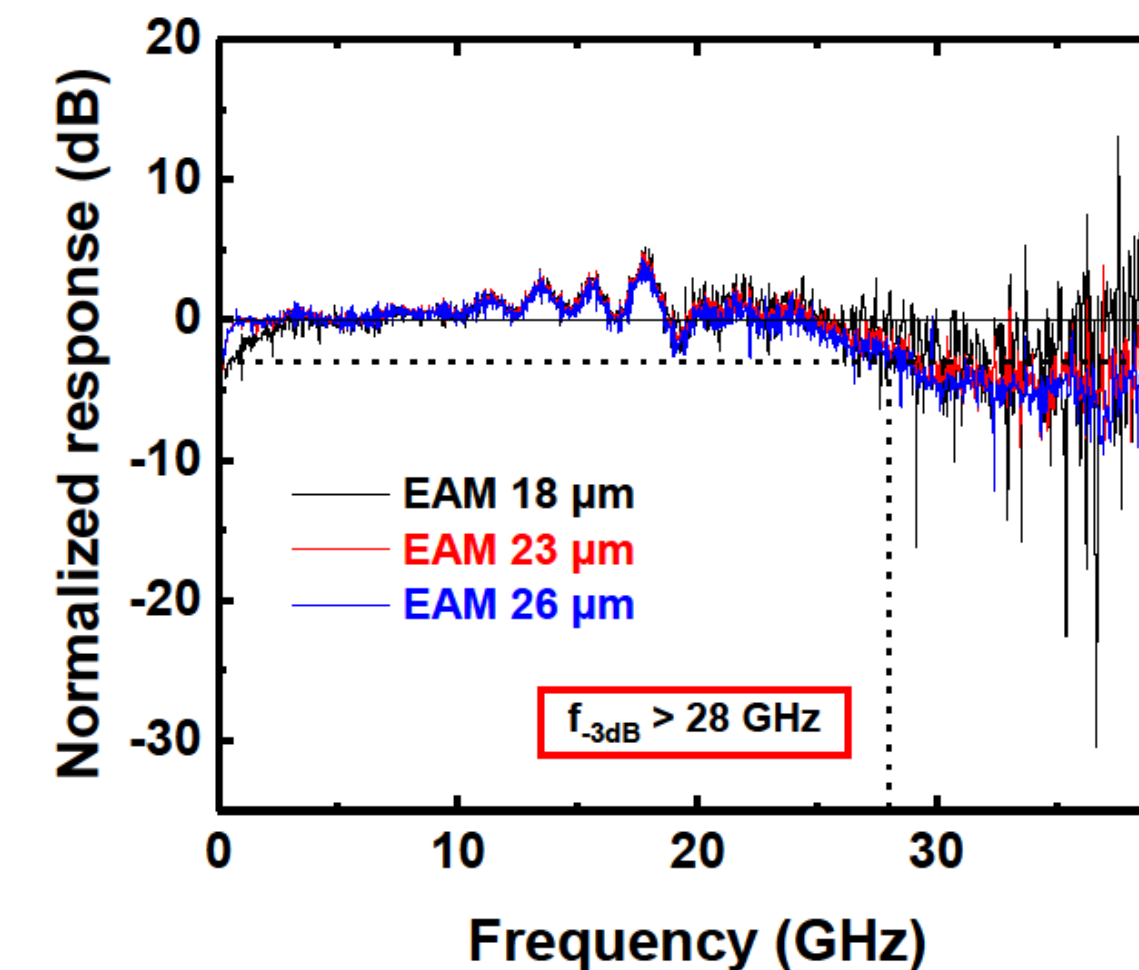
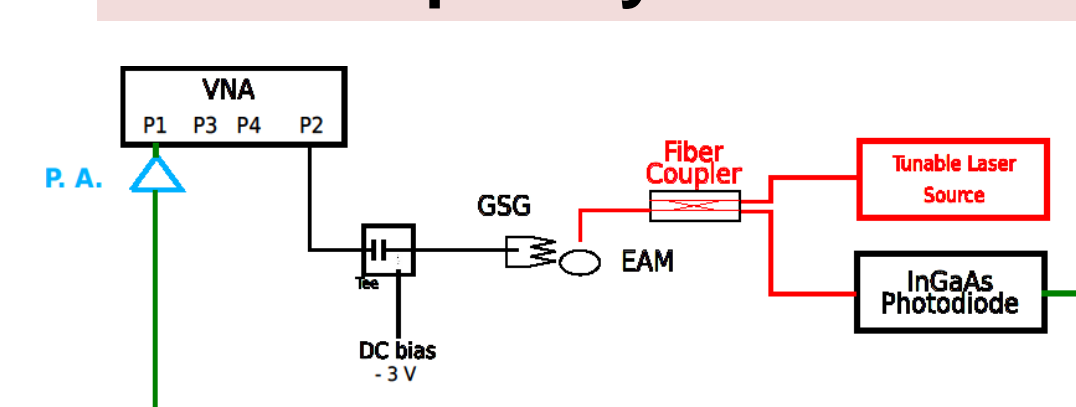
#### Bias field / temperature effect on contrast ratio : measurements vs modelling



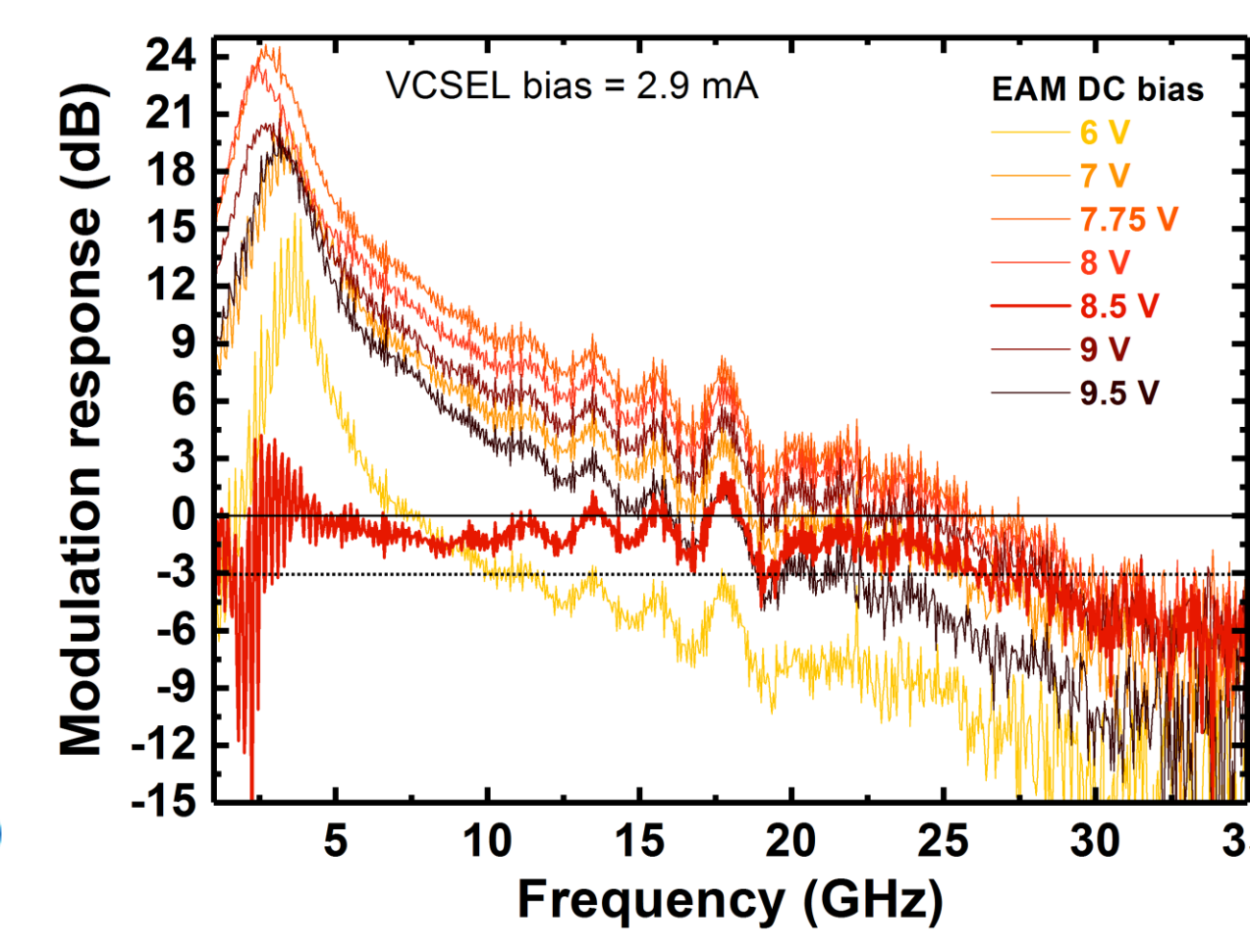
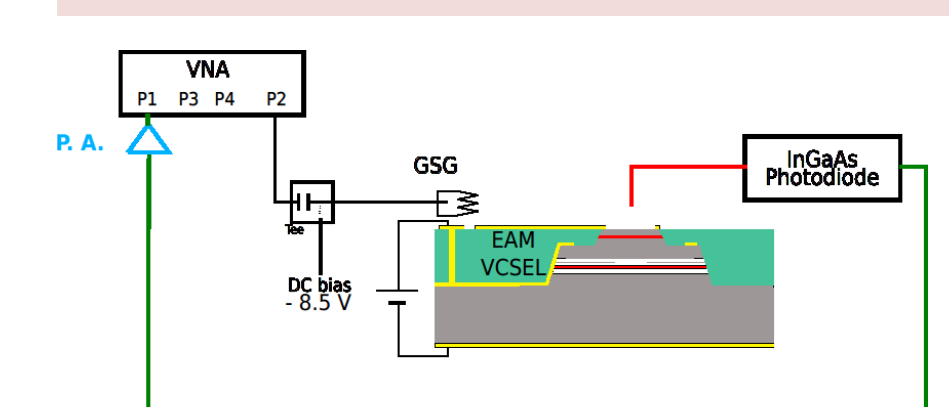
#### Efficient modulation on EAM-VCSEL device

### High frequency performance

#### EAM frequency bandwidth



#### EAM-modulated VCSEL



### Modulation bandwidth demonstrated on EAM and EAM-VCSEL at 29-30 GHz

L. Marigo-Lombart et al., J. Phys. Photonics 1 02LT01 (2019)

## Achievements

- Vertically integrated VCSEL / Electro-absorber modulator (EAM) : Original and efficient approach for overpass the limits of directly-modulated VCSELS
- Technological bricks for the fabrication of complex three-electrodes EAM-VCSEL device : MBE growth, simplified self-aligned process flow, BCB planarization
- Design/modelling and characterization of static electro-optical behavior of the EAM modulator
- Design/modelling and characterization of RF access up to 110 GHz : BCB, microstrip geometry
- High frequency (up to 40GHz) characterization of the vertical asymmetric Fabry-Perot modulator : 29-30 GHz bandwidth demonstrated

First demonstration of EAM-modulated VCSEL up to 29 GHz (Current record on directly-modulated VCSEL : 35GHz (TU Berlin))