29GHz-bandwidth monolithically integrated EAM-VCSEL

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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 (Kuchta et al., PTL, 2015)
Others approaches to increase VCSEL bandwidth:
- T-VCSEL (KTH, Amin et al., OE, 2014)
- Coupled-Cavity VCSEL (Dair et al., AOE, 2015)
- 6-VCSELs arrays (6x40 Gb/s = 240 Gb/s) (Westbergh et al., PTL, 2015)
- Dual-cavity VCSEL (Van Eidsen 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

High-speed modulation with VCSELs

Original technological bricks developments:
- Molecular beam epitaxy:
  - Double microcavity stack,
  - Digital alloyed QWs (EAM),
  - Monitoring: reflectometry, optical flux monitoring (OFM), water curvature
- Self-aligned lithographic process flow:
  - etching / passivation / metallization
- BCB planarization:
  - mechanical patterning step (nanoimprint) / ICP etching
- RF design of the contact pads:
  - Microstrip geometry

Fabrication technology

EAM-VCSEL characterizations

Static electro-optical characterizations

- Wavelength detuning:
  - Reflectivity / gain & absorber
- Bias field / temperature effect on contrast ratio:
  - measurements vs modelling

Influences of biased field / temperature

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

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))