P2-138

SiO_2 clad active and passive photonic crystal nanocavity devices fabricated with photolithography

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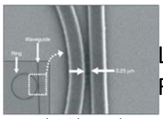
Abstract

We describe the fabrication and a demonstration of passive and active photonic crystal nanocavity devices, namely an electro-optic modulator, an all-silicon photodetector and a DeMUX filter. This is the first demonstration of active and passive photonic crystal nanocavity devices fabricated with a photolithographic process that may lead to future mass production.

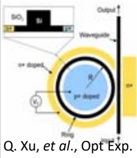
Background



Low energy : 25 pJ

Response time : ~450 ps

V.R. Almeida, *et al.*, Nature **431**, 1081 (2004)



Conversion E → O

- pn dope region
- Speed: 12.5 Gbit/s

Q. Xu, *et al.*, Opt Exp. **15**, 430 (2007)

PhC nanocavity
- ✓ High Q factor **Q/V**
- ✓ Small mode volume, V

Energy-efficient optical signal processing

Problems

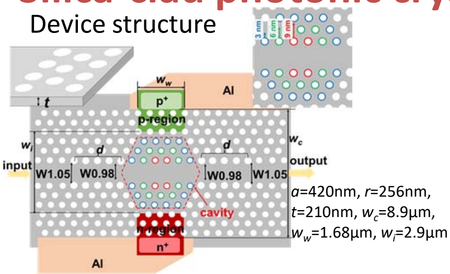
1. EB-lithography
2. Air-bridge structure

Solution

1. Photolithography fabrication w/ silica clad

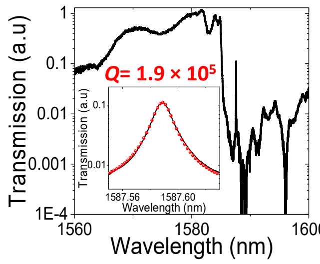
Silica-clad photonic crystal nanocavity

Device structure



a=420nm, r=256nm, t=210nm, w_c=8.9µm, w_w=1.68µm, w_i=2.9µm

Transmission spectrum



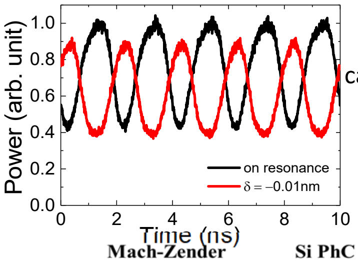
Image

- High Q factor
- Stable and robust

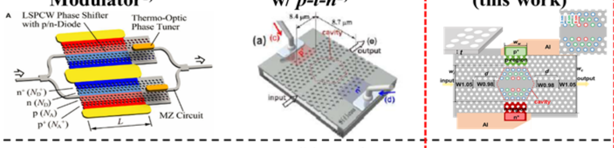
Y. Ooka, et al., Sci. Rep. 5, 11312 (2015)

Active devices

Electro-optic modulator



0.5 GHz modulation based on carrier plasma dispersion effect.



	Mach-Zender Modulator[1]	Si PhC nanocavity w/ *p-i-n*[2]	Si PhC nanocavity (this work)
Fabrication process	**Photolithography (easy)**	EB lithography (complicated)	**Photolithography (easy)**
Structure	**Silica clad**	Air-bridge	**Silica clad**
Size	400µm × 500µm	**10µm × 5µm**	**10µm × 5µm**
Speed	**10GHz**	100GHz	100GHz
Voltage	5V	**2V**	**2V**

1) Y. Terada, *et al.*, Frontiers in Physics, Vol.2 (2014)
2) T. Tanabe, *et al.*, Opt. Lett. 23, 3895 (2010)

Photo-receiver

Transmission-current at resonance wavelength

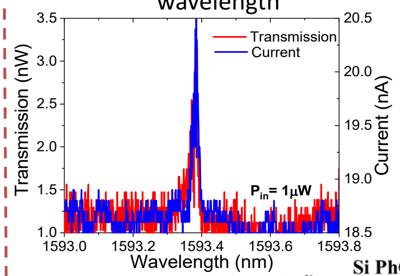
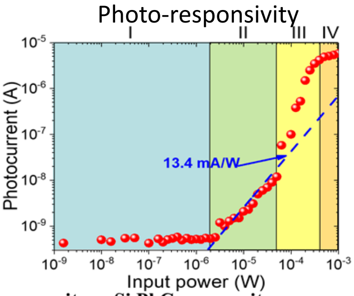


Photo-responsivity

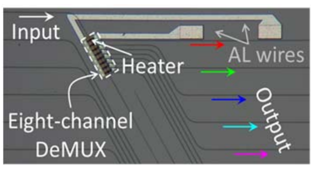


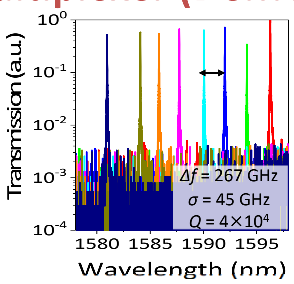
	Ge on Si [1]	Si PhC nanocavity w/ *p-i-n*[2]	Si PhC nanocavity (this work)
Footprint	10µm×10µm	**10µm×5µm**	**10µm×5µm**
Structure	Deposition Ge on Si	EB lithography Air-bridge	**Photolithography SiO_2 cladding**
Bias voltage	-4 V	**-3 V**	**-3 V**
Responsivity	**3.2 (A/W)**	0.016 (A/W)	0.013 (A/W)
Quantum efficiency	**>300 %**	9.7 %	0.89 %
Leak current	1 µA	15 pA	**12 pA**
Coupled w/ fiber	-	-12 dB	**-1.6 dB**

1) T. Yin, et. al., Group IV Photonics (GFP), 2016 IEEE 13th International Conference on. 2016 Aug, IEEE, pp. 20-21 (2016)
2) T. Tanabe, et. al., Opt. Lett. 23, 3895 (2010)

Passive device : Demultiplexer (DeMUX)

Eight-channel demultiplexer





Stability & Structure	Fabrication	# of channels	Channel spacing	Configuration	Footprint per channel	Other remarks	Reference
High & PhC **SiO_2 clad**	**Photo-lithography**	8	267 GHz	**In-plane**	110 µm²	**WM cavity**	**This work**
Low & PhC Air-bridge	EB lithography	5	3.7 THz	In-plane	30 µm²	L3 cavity	OE **14**, 12394 (2006)
Low & PhC Air-bridge	EB lithography	32	100 GHz	Out-plane	100 µm²	L3 cavity	OE **22**, 4698 (2014)
High & Si-AWG	Photo-lithography	8	250 GHz	In-plane	1700 µm²	-	OE **22**, 4698 (2014)

Summary

1. We demonstrated the active and passive devices fabricated using photolithographic SiO_2 clad PhC nanocavity devices.
2. We showed that 0.5 GHz modulation is possible with a p-i-n integrated PhC nanocavity.
3. We also obtained 13.4 mA/W responsivity for the photodetector at input powers of less than 10 µW and low dark current.
4. Finally, we demonstrated of a multichannel passive DeMUX filter with SiO_2 clad photolithographic PhC nanocavity.

Acknowledgement & Publications

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1. N.A.B. Daud, *et al.*, "Electro-Optic Modulator Based on Photolithography Fabricated p-i-n Integrated Photonic Crystal", IEICE Transaction on Electronics, (2017) (accepted)
2. Y. Ooka, N. A. B. Daud, *et al.*, "Ultrasmall in-plane photonic crystal demultiplexers fabricated with photolithography", Opt. Express 25, 1521-8 (2017).