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Harnessing giant Brillouin gain for advanced integrated microwave signal processing

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14. ABSTRACT
Several major achievements are:
1. Onchip processing of optical signals using Brillouin scattering demonstrated for highcapacity communications
2. Worldrecord onchip Brillouin gain of 52 dB with net gain of 47 dB
3. Multiple simultaneous notch responses demonstrated using the SBS chip. The current maximum number of notches is 3
4. Onchip True time delay demonstrated
5. Concept of phase amplification employed to amplify the phase by 10 times.
6. A microwave photonic processor capable of phase shift, delay and filtering demonstrated
7. We combined silicon nitride technology with fibrebased SBS to demonstrate a lossless RF photonic notch filter
8. We used silicon nitride technology to demonstrate an onchip alloptimized filter
9. Using silicon nitride technology we demonstrated a delay line with a tuning speed >1 GHz
10. Dr Eric Magi visited the US Army Research Lab in Adelphi, Maryland in early 2017 to demonstrate the Microwave photonic filter prototype filter to key stakeholders from the US defence sector.
Total of 12 published papers, 13 invited talks, and received additional funding from AUD.

15. SUBJECT TERMS
Brillouin scattering, microwave photonic devices, Brillouin amplifier, on-chip microwave photonic

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Final Report

12 April 2019

Title: Harnessing giant Brillouin gain for advanced integrated microwave signal processing

Affiliation: School of Physics, University of Sydney

Principal Investigators (PIs): Prof. Benjamin J. Eggleton, Dr. Amol Choudhary, Dr. David Marpaung

Abstract:

With a recent breakthrough in the design and fabrication of chalcogenide waveguides, we have obtained on-chip Brillouin gain in excess of 50 dB which has opened the doors to the realization of various important on-chip signal processing functionalities. The aim of this proposal is to exploit this high on-chip gain to realize microwave photonic functionalities that were earlier unachievable. We will realize on-chip microwave photonic filters with a reconfigurable bandwidth and high frequency tunability with a low pass-band ripple to demonstrate microwave photonic channelizers. Channelizers are important devices for limiting the noise to increase the signal-to-noise ratio. We will also demonstrate multiple notch filters and tunable true time delay. We will investigate the physics of stimulated Brillouin noise build-up in the context of realizing Brillouin amplifiers. The demonstration of a low-noise Brillouin amplifier would be paramount for the realization of an all optical-phononic chip for microwave signal processing.

Executive Summary

- Project Commenced in September 2016, USD60,000 for year 1, and USD50,000 subject to approval.
- Major achievements:
    1. On-chip processing of optical signals using Brillouin scattering demonstrated for high-capacity communications
    2. World-record on-chip Brillouin gain of 52 dB with net gain of 47 dB
    3. Multiple simultaneous notch responses demonstrated using the SBS chip. The current maximum number of notches is 3
    4. On-chip True time delay demonstrated
    5. Concept of phase amplification employed to amplify the phase by 10 times.

6. A microwave photonic processor capable of phase shift, delay and filtering demonstrated
7. We combined silicon nitride technology with fibre-based SBS to demonstrate a lossless RF photonic notch filter
8. We used silicon nitride technology to demonstrate an on-chip all-optimized filter
9. Using silicon nitride technology we demonstrated a delay line with a tuning speed >1 GHz
10. Dr Eric Magi visited the US Army Research Lab in Adelphi, Maryland in early 2017 to demonstrate the Microwave photonic filter prototype filter to key stakeholders from the US defence sector.

1. Published papers with AOARD acknowledgement:

1. E. Giacoumidis, A. Choudhary, E. Magi, D. Marpaung, B. Corcoran, M. Pelusi, and B. J. Eggleton, "Chip-based Brillouin processing for energy-efficient and low latency self-coherent optical communications," Optica 5, 1191-1199, 2018
2. Y. Liu, D. Marpaung, B.J. Eggleton, and A. Choudhary, "High-Performance Chip-based Microwave Photonic Functionalities," IEEE Photonics Technology Letters, 30, 1822 – 1825, 2018 (Invited)
3. A. Choudhary, Y. Liu, D. Marpaung, B. J. Eggleton, "On-chip Brillouin filtering of RF and Optical Signals," IEEE Journal of Selected Topics in Quantum Electronics, Accepted, 6, 2018 (Invited)
4. Y. Liu, D. Marpaung, A. Choudhary, J. Hotten, B. J. Eggleton, "Link Performance Optimization of Chip-based Si3N4 Microwave Photonic Filters," IEEE Journal of Lightwave Technology, 6, 2018
5. Y. Liu, A. Choudhary, D. Marpaung, B. J. Eggleton, "Chip-based Brillouin Processing for Phase Control of RF Signals," IEEE Journal of Quantum Electronics, 54, 1-13, 2018 (Invited)
6. A. Choudhary, Y. Liu, K. Vu, P. Ma, S. Madden, D. Marpaung, B.J. Eggleton, "Narrowband gain in chalcogenide waveguides for low-power RF delay lines," Proc. SPIE 10683, Fiber Lasers and Glass Photonics: Materials through Applications, 1068308
7. Y. Liu, J. Hotten, A. Choudhary, B. J. Eggleton, D. Marpaung, "All-optimized integrated RF photonic filter," Optics Letters, 42, 4631-4634, 2017 (Editor's Pick)
8. A. Choudhary, Y. Liu, B. Morrison, K. Vu, D-Y. Choi, P. Ma, S. Madden, D. Marpaung, and B. J. Eggleton, "High-resolution, on-chip RF photonic signal processor using Brillouin gain shaping and RF interference" Scientific Reports, 7, 5932, 2017

9. Y. Liu, A. Choudhary, D. Marpaung, B. J. Eggleton, “Gigahertz optical tuning of an on-chip radio frequency photonic delay line,” Optica, 4, 418-423, 2017
10. A. Choudhary, B. Morrison, I. Aryanfar, S. Shahnia, M. Pagani, Y. Liu, K. Vu, S. Madden, D. Marpaung, and B. J. Eggleton, “Advanced microwave photonic signal processing with giant on-chip Brillouin gain,” Journal of Lightwave Technology, 35, 846-854, 2017 (Invited)
11. I. Aryanfar, D. Marpaung, A. Choudhary, Y. Liu, K. Vu, D. Yong Choi, P. Ma, S. Madden, and B. J. Eggleton, “Chip-based Brillouin RF photonic phase shifter and wideband time delay,” Optics Letters, 42, 1313-1316, 2017
12. Y. Liu, D. Marpaung, A. Choudhary, B. J. Eggleton, “Lossless and high-resolution RF photonic filter,” Optics Letters, 41, 5306-5309, 2016 (Editor’s Pick)

2. Paper currently under review funded by AOARD grant (journal name, title, date accepted): N/A

3. Published papers funded by cost Sharing/other sources but related to AOARD grant (Journal name, title, date):

- B. Morrison, A. Casas-Bedoya, G. Ren, K. Vu, Y.Liu, A. Zarifi, T. G. Nguyen, D-Y. Choi, D. Marpaung, S. Madden, A. Mitchell, B. J. Eggleton, “Compact Brillouin devices through hybrid integration on Silicon,” Optica (In Press)

4. Conference paper/poster/presentation funded by AOARD grant (conf. name, title, date):

- Y. Liu, A. Choudhary, G. Ren, K. Vu, B Morrison, A. Casas-Bedoya, T. G. Nguyen, D.-Yong Choi, A. Mitchell, S. J. Madden, D. Marpaung, and B. J. Eggleton, “Integrating Brillouin processing with functional circuits for enhanced RF photonic processing,” International topical meeting on microwave photonics (MWP), Toulouse, France, 2018
- A. Choudhary, Y. Liu, D. Marpaung, and B. J. Eggleton, “Low-noise and high-linearity RF filtering using Brillouin loss” SPIE Optics and Photonics, San Diego, USA, 2018
- A. Choudhary, Y. Liu, D. Marpaung, and B. J. Eggleton, “Brillouin Filtering with Enhanced Noise Performance and Linearity Using Anti-Stokes Interactions,” CLEO, San Jose, USA,2018
- Y. Liu, D. Marpaung, A. Choudhary, J. Hotten and B. J. Eggleton “Sub-20-dB Noise Figure and Positive Link Gain in a Chip-based Si3N4 Microwave Photonic Filter,” International topical meeting on microwave photonics (MWP), Beijing, China, 2017
- A. Choudhary, N. G. Seil, M. Pelusi, K. Vu, D. Yong Choi, P. Ma, S. Madden, D. Marpaung, B.J. Eggleton, “Linearity and resolution of on-chip SBS filters for RF and optical communications,” CLEO Pacific Rim, Singapore, 2017

- Y. Liu, J. Hotten, A. Choudhary, B. J. Eggleton, D. Marpaung, "Lossless integrated RF photonic filter with record-low noise figure and 116 dB of dynamic range," CLEO Pacific Rim, Singapore, 2017 **(Postdeadline)**
- I. Aryanfar, A. Choudhary, Y. Liu, K. Vu, D. Yong Choi, P. Ma, S. Madden, D. Marpaung, and B. J. Eggleton, "47 dB Net on-chip Brillouin gain for true time delay applications," CLEO, San Jose, USA, 2017
- Y. Liu, A. Choudhary, D. Marpaung, and B. J. Eggleton, "Gigahertz tuning of on-chip RF photonic delay line," CLEO, San Jose, USA, 2017
- Y. Liu, D. Marpaung, A. Choudhary, B. J. Eggleton, "Highly selective and reconfigurable Si3N4 RF photonic notch filter with negligible RF losses," CLEO, San Jose, USA, 2017
- A. Choudhary, Y. Liu, I. Aryanfar, B. Morrison, K. Vu, D. Yong Choi, P. Ma, S. Madden, B. Luther-Davies, D. Marpaung, and B. J. Eggleton "Amplitude and phase control of RF signals using on-chip stimulated Brillouin scattering" International Conference on Fibre Optics and Photonics, Kanpur, India, Tu2F.4, 2016

5. Invited talks (event name, title, date):

1. Y.Liu, A. Choudhary, D.Marpaung, B.J.Eggleton, "Brillouin circuits for high-performance microwave photonic applications," ACP, Hangzhou, China, 2018
2. Y. Liu, J. Hotten, A. Choudhary, D. Marpaung, B. J. Eggleton, "All-optimized integrated microwave photonic bandstop filter," OECC, Jeju, Korea 2018
3. B. J. Eggleton, A. Choudhary, "Brillouin photonic integrated devices for ultrahigh-resolution and broadband microwave signal processing," International Frequency Control Symposium, Olympic Valley, USA, 2018
4. A. Choudhary, "High-resolution integrated microwave photonic signal processing," International Conference on Microwave and Photonics (ICMAP), Dhanbad, India, 2018
5. B.J. Eggleton, and A. Choudhary, "Harnessing photon-phonon interactions in nanoscale circuits for microwave and telecom photonic signal processing," International Conference on Fibre Optics and Photonics, Kanpur, India, W4F.1, 2016
6. B. J. Eggleton, and A. Choudhary, "Good Vibrations: Controlling light with sound", SPIE Optics and Photonics, San Diego, USA, 9956-39, 2016
7. B.J. Eggleton, Tutorial "Inducing and harnessing photon-phonon interactions in photonic integrated circuits", Asia Communications & Photonics Conference, Wuhan, P.R. China, November 2016.
8. B. J. Eggleton, Tutorial, "Stimulated Brillouin scattering in photonic integrated circuits", IEEE Photonics Annual meeting, Hawaii, October 2016.
9. B.J. Eggleton, Tutorial, "Harnessing Photon-phonon Interactions in Photonic Integrated Circuits", OSA Latin America Optics & Photonics Conference, Medellin Colombia, August 2016.

10. B.J. Eggleton, Keynote presentation, “Inducing and Harnessing Hypersound Acoustic Phonons in Photonic Integrated Circuits,” 2016 International Conference on Optical MEMS and Nanophotonics (OMN), Singapore, August 2016.
11. B.J. Eggleton, Keynote presentation, “Good vibrations: controlling light with sound in phononic chips,” PECS-XII, York, UK, July 2016.
12. B.J. Eggleton, Invited paper, “Nonlinear optical phononics: Harnessing light-sound interactions in nanoscale integrated circuits,” NUSOD 16th International Conference, Sydney, Australia, July 2016.
13. D. Marpaung, "On chip SBS for MWP Signal Processing Applications", Optical Fiber Communication Conference and Exposition (OFC) 2016, 20-24 March 2016, Anaheim, CA.

6. Award for best paper, best poster (title, date): N/A

7. Received additional fund for your research efforts related to AOARD grant
(name, amount, date):

- On-chip generation and processing of high-power multi-GHz frequency combs, AUD 365,000, 2018-2020
- High-speed RF generation and detection architecture, AUD 179,000, 2018-2019

8. IP disclosure/Patent/Patent submitted (title, date submitted): NA

9. Visited AFRL/DoD installation in US, including under AOARD WoS program
(Location, date):

- Dr Eric Magi visited the US Army Research Lab in Adelphi, Maryland in early 2017 to demonstrate the Microwave photonic filter prototype filter to key stakeholders from the US defence sector.