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Low-loss single-mode waveguides operating at UV/violet wavelengths and fabricated with contact optical lithography

Student Paper

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ABSTRACT

We demonstrate air-cladding single-mode waveguides operating at ultraviolet (UV) wavelengths with propagation loss of 5 dB/cm at λ =402 nm. The waveguides are fabricated with atomic layer deposition (ALD) of aluminium oxide (AlO_x) on SiO_2/Si substrates and with contact optical lithography. This enables an efficient, cost-effective and fast processing. Our result paves the way for on-chip UV spectroscopy.

Keywords: UV, integrated photonic circuits, low-loss waveguides, AlO_x waveguides, ALD

1. INTRODUCTION

Integrated photonics is an enabling technology in diverse fields of applications, including optical communications and biological sensing. In particular, on-chip bio-sensing arouses great interest, due to its potential in terms of low-cost, compactness and low detection limit. CMOS-compatible silicon nitride (SiN_x), which is currently playing an important role for on-chip spectroscopy, is the material of choice for visible/near infrared (NIR) platforms [1]. However, SiN_x suffers from high absorption loss at blue/UV wavelengths [2]. Much effort has been devoted to investigate waveguides at UV wavelengths, yet the UV platform is still in its infancy. For an ideal photonic platform, both low-loss and single-mode operation are crucial to combine multiple optical components on chip. Recently, X. Liu et.al [3] reported a single crystal AlN platform. Benefiting from the excellent film quality, moderate waveguide-loss of 8 dB/cm at λ =390 nm was reached. Nevertheless, the large waveguide-dimension and high index (n) value of 2.2 lead to multi-mode guidance even using electron-beam lithography. In contrast, aluminium oxide (AlO_x) has a lower refractive index value and high transparency above 220 nm [4]. Using atomic layer deposition (ALD), the uniformity and thickness of AlO_x film can be well controlled. G.N. West et al. demonstrated AlO_x waveguides with an impressive low loss of ~3 dB/cm at λ =371 nm [5]. Stepper lithography was needed to pattern waveguides and then to achieve single mode operation. Besides, their platform implements silicon oxide (SiO_x) as hard mask which is kept as top-cladding afterward. Although this will efficiently decrease the index contrast between the core and cladding and then reduce the scattering loss, the SiO_x-cladding will inevitably inhibit the bio-sensing potentials of the platform. In this paper, we propose air-cladding single-mode AlO_x waveguides fabricated by conventional contact photolithography (Karl Süss MA6 aligner). Prior to implement the expensive and time-consuming stepper lithography, this AlO_x platform makes use of an efficient and cost-effective lithography tool to make research prototypes of devices in UV/violet spectrum. Propagation loss of 5 dB/cm is demonstrated at a wavelength of 402 nm.

2. DESIGN AND CHARACTERIZATION OF ALOX WAVEGUIDES

We have used the simulation tool COMSOL Multiphysics to investigate the range of single-mode operation of the AlO_x waveguides. The AlO_x layer is grown on 3-μm thermal SiO_2 on Si wafers. The thickness of AlO_x layer is designed to be 120 nm for λ =402 nm, while 100 nm is adopted for λ =360 nm to inhibit high-order TE modes. To make sure that the designed waveguide supports only a TE-guided mode, we have simulated the evolution of the modal effective index with respect to the waveguide-width. The results are plotted in Fig. 1(a). With air top-cladding, the cut-off width of the single-mode operation is as large as 1190 nm and 1150 nm for λ=402 nm and 360 nm, respectively. The TE modal profiles of the simulated AlO_x waveguide at λ =402 nm and 360 nm are shown in Fig. 1(b).

To precisely control the thickness and quality of the core layer, AlOx film is deposited on SiO_2/Si wafer via ALD using an Ultratech Savannah 200 instrument (Veeko). AlO_x is deposited at 150°C using trimethylaluminum and water as precursors. Due to the poor etching selectivity between the photoresist and the AlO_x, a layer of SiN_x

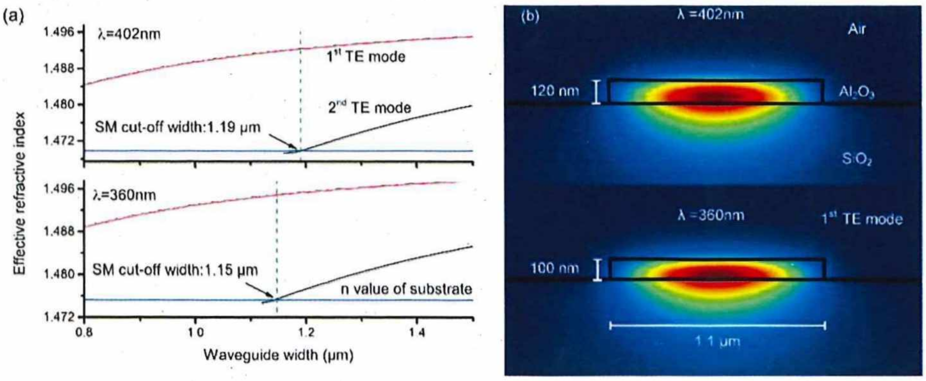

Figure 1. (a) Evolution of 1st and 2nd TE mode effective index with respect to waveguide width at λ =402 nm and 360 nm, respectively. (b) Simulated modal profiles of the designed waveguide for λ=402 nm and 360 nm.

grown by plasma enhanced chemical vapour deposition (PECVD) is used as hard mask to define the AlO_x waveguides. We have used a conventional mercury lamp based contact photolithography system with a band pass filter selecting the 280-350 nm wavelength range to expose the photoresist. The patterns defined by the photoresist are transferred to the SiN_x hard mask by using reactive ion etching (RIE). The AlO_x layer is dry etched in an inductive coupled plasma (ICP)-RIE with a $BCl_3/Cl_2/Ar$ gas mixture. The anisotropy of the etching of both SiN and AlO_x are well controlled, resulting in nearly vertical side walls. Finally, the SiN hard mask is removed by RIE. A typical cross-section of a waveguide is shown in Fig. 2(b). The fabricated waveguide with a width of 1100 nm and height of 120 nm is characterized using a 402 nm diode laser. The top image of the light scattered from a 1.6 cm-long spiral waveguide is shown in Fig. 2(a). The 200 μm bend radius is designed to minimize bend losses. The propagation loss is estimated to be ~5 dB/cm by analysing the intensity decay of scattered light. The intensities of scattering light at input and output are extracted and averaged by 20 lines of pixels, as shown in Fig. 2(c). The total waveguide loss is attributed to material absorption and scattering loss. With the higher deposition temperature of 300 °C, the material absorption of ALD AlO_x can be further decreased [4]. Meanwhile, waveguides designed to operate at λ =360 nm are under processing.

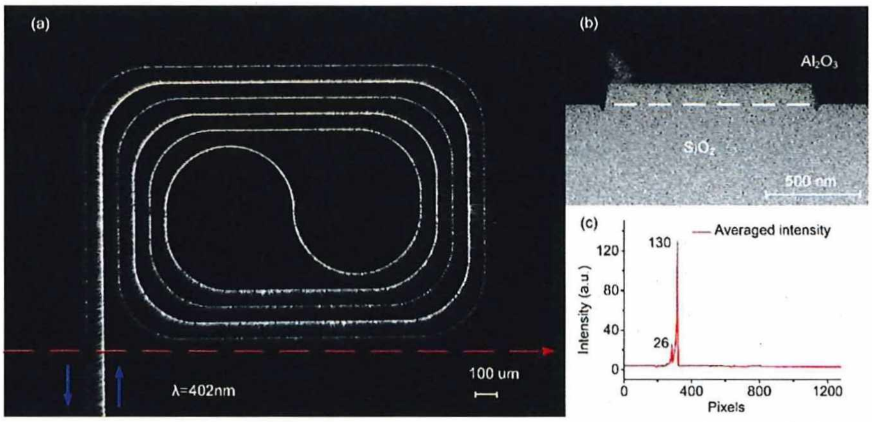

Figure 2. (a) Microscopy images of the scattered light from a spiral waveguide at a wavelength of 402nm, (b) Cross-section of the corresponding AlO_x waveguide imaged by a scanning electron microscope, (c) Averaged intensity profile of the scattered light at the input and output of the spiral. The total length of the spiral equals to 1.6 cm.

3. CONCLUSIONS

This work paves the way for on-chip light-matter interaction in the UV/violet region, and in particular for on-chip UV spectroscopy. Furthermore, being compatible with contact optical lithography, the proposed AlO_x platform exhibits the advantage of fast processing and low-cost. Finally, the achieved 5 dB/cm-loss single-mode waveguides are promising for developing a UV platform with complex on-chip optical components.

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13:15 - 14:15	**Poster Session 1 // Light sources and amplifiers** Chair: Laurent Vivien (Univ. Paris Saclay, CNRS, C2N, France)	
	Arab N 1, Poette J 1, Bastard L 1, Broquin J-E 1 1Univ. Grenoble Alpes, CNRS, Grenoble INP, IMEP-LAHC, 38000 Grenoble, France	Dual wavelength Y-junction glass integrated waveguides for mm-wave carrier generation
	Aref Rasoulzadeh Zali1, Steven Kleijn2, Luc Augustin2, Ripalta Stabile1, Nicola Calabretta1 1 IPI-ECO research institute, Eindhoven University of Technology, Eindhoven, the Netherlands 2 Smart Photonics, High Tech Campus, Eindhoven, the Netherlands	Low Polarization Sensitive Semiconductor Optical Amplifier Co-Integrated with Passive Waveguides for Optical Datacom and Telecom Networks
	Qin Zou, Kamel Merghem, Badr-Eddine Benkelfat, Musharrat Shabnam Samovar, CNRS, Télécom SudParis, Institut Polytechnique de Paris, 19 place Marguerite Perey, 91120 Palaiseau, France	Bifurcation and Chaotic Behavior of Feedback Semiconductor Lasers Operating in the Full Range of External Reflectivity
	Julio Darío López1, Dan Zhao2,3, Mu-Chieh Lo4,*, Robinson Guzmán1,, Xaveer Leijtens2, and Guillermo Carpintero1 1Universidad Carlos III de Madrid, Leganés, Spain 2Technische Universiteit Eindhoven, Eindhoven, Netherlands 3now with ASML, Veldhoven, Netherlands 4University College London, London, UK	Narrow-Linewidth DBR Laser Using Open-Access High-Precision Grating in InP PIC Generic Foundry Platform
	Mariangela Gioannini1, Lorenzo Columbo1, Antonino Bologna1, Marco Novarese1, Sebastian Romero- García2, Dominic Siriani2, Jock Bovington2 1 Department of Electronics and Telecommunication, Politecnico di Torino (Italy) 2 Cisco Systems, San Jose, CA, (US)	Design of hybrid lasers for silicon photonics: efficiency, optical feedback tolerance and laser dynamics
	Junfei Xia, Qixiang Cheng*, Tongyun Li, Richard V. Penty Centre for Photonic Systems, Electrical Engineering Division, Department of Engineering, University of Cambridge, 9 JJ Thomson Avenue, Cambridge CB3 0FA, UK.	The Design of Hybrid III-V on Silicon Optical Switch based on Mach-Zehnder and SOA Switching Elements
	E. Malysheva, A. Fiore, K.A.Williams, V.Dolores-Calzadilla Institute for Photonic Integration, Eindhoven University of Technology, Eindhoven, The Netherlands	Manufacture-compliant InP-based metal cavity nanolaser design
	Jack Mulcahy 1,2, John McCarthy1,2, Mohamad Dernaika 3, Albert A. Ruth 4, Satheesh Chandran 4, Prince M. Anandarajah 5, Eamonn P. Martin 5, Justin K. Alexander 6 & Frank H. Peters 1,2 1Tyndall National Institute, Lee Maltings, Cork, Ireland 2Physics Department, University College Cork, Cork, Ireland 3Rockley Photonics Ireland, Lee Mills House, Lee Maltings, Cork, Ireland 4Physics Department & Environmental Research Institute, University College Cork, Cork, Ireland 5School of Electronic Engineering, Dublin City University, Glasnevin, Dublin 9, Ireland	Monolithically Integrated Wavelength Tunable Dual Comb Source using Gain Switching
	Juan Navarro-Arenas, 1 Andrés F. Gualdrón-Reyes,2-3 Vladimir S. Chirvony, 1 Iván Mora-Seró,2 Juan Martínez-Pastor1 and Isaac Suárez 4 1 Instituto de Ciencia de Materiales (ICMUV), Universidad de Valencia, C/ Catedrático José Beltrán, 2, 46980 Paterna, Spain. 2 Institute of Advanced Materials (INAM), University Jaume I, Avenida de Vicent Sos Baynat, s/n, 12006 Castelló de la Plana, Castellón, Spain. 3 Biofuels Lab-IBEAR, Faculty of Basic Sciences, University of Pamplona, Pamplona, Colombia, C. P. 543050. 4 Escuela Técnica Superior de Ingeniería, Universidad de Valencia, C/Avenida de la Universidad s/n 46100 Burjassot, Valencia, Spain.	Perovskite Nanocrystals: an Active Material for Integrated Optics
	Sander Reniers 1, Kevin Williams 1, Jos van der Tol 1, Yuqing Jiao 1 1Institute for Photonic Integration (IPI), Eindhoven University of Technology	An Accurate Characterization Method for Polarization Converters on the Indium Phosphide Membrane on Silicon Platform
	Stanisław Stopiński, Krzysztof Siwiec, Witold Pleskacz, Sławomir Szostak, Ryszard Kisiel and Ryszard Piramidowicz Warsaw University of Technology, Institute of Microelectronics and Optoelectronics, Koszykowa 75, 00-662 Warsaw, Poland	Hybrid Integration of a Single-Frequency Ring Laser with a Microelectronic Driver
	Zhengrui Tu1, Jianhao Zhang1, John Rönn2, Carlos Alonso-Ramos1, Xavier Leroux1, Laurent Vivien1, Zhipei Sun2, Éric Cassan1 1 Centre de Nanosciences et de Nanotechnologies (C2N), UniversitéParis Saclay, UniversitéParis Sud, CNRS, 91120 Palaiseau, France 2 Department of Electronics and Nanoengineering, Aalto University, Tietotie 3, FI-00076 Espoo, Finland	Prospect for compact on-chip lasing with hybrid erbium-doped silicon integration

13:15 - 14:15	**Poster Session 2 // New technology, new materials, new modeling for nonlinear and passive devices** Chair: Delphine Marris-Morini (Univ. Paris Saclay, CNRS, C2N, France)	
	Chupao Lin 1, 2, David Schaubroeck 3, Gunther Roelkens1, 2, Roel Baets1, 2 and Nicolas Le Thomas1, 2 1 Photonics Research Group, INTEC Department, Ghent University-imec, Technologiepark-Zwijnaarde, 9052 Ghent, Belgium 2 Center for Nano- and Biophotonics, Ghent University, Belgium 3Centre of Microsystems Technology (CMST), imec and Ghent University, Technologiepark 126, B-9052 Zwijnaarde, Belgium	Low-loss single-mode waveguides operating at UV/violet wavelengths and fabricated with contact optical lithography
	Jianhao Zhang,1 Carlos Alonso-Ramos,1 Laurent Vivien,1 Sailing He,2 Eric Cassan1 1 UniversitéParis-Saclay, Univ. Paris-Sud, CNRS, Centre de Nanosciences et de Nanotechnologies, 91120, Palaiseau, France. 2 State Key Laboratory for Modern Optical Instrumentation, Centre for Optical and Electromagnetic Research, Zijingang Campus, Zhejiang University, Hangzhou 310058, China	Ultra-wide band inter-mode four-wave mixing in sub-wavelength silicon waveguides
	Pragati Aashna1 and K Thyagarajan2 1Department of Physics, Indian Institute of Technology Delhi, Delhi, 110016 2Department of Physics, School of Engineering and Applied Sciences, Bennett University, Greater Noida, UP, 201310	Two-process frequency conversion under stimulated Raman adiabatic passage via a continuum of dark intermediate modes
	Benedicto D1, Días A2, Martín JC1, Vallés JA2, Solís J2 1 Department of Applied Physics and I3A, Faculty of Sciences, University of Zaragoza, C/ Pedro Cerbuna 12, 50009 Zaragoza (Spain). 2 Laser Processing Group, Instituto de Óptica "Daza de Valdés", CSIC, C/ Serrano 121, 28006 Madrid (Spain).	Characterization of an Er3+/Yb3+ Codoped Two Core Integrated Waveguide Femtosecond Laser written in a Phosphate Glass
	J.-B. Dory1,2, J.-Y. Raty1,3, M. Ibnoussina2, J.-B. Jager4, A. Verdy1, F. d'Acapito5, M. Tessaire1, M. Bernard1, P. Colman2, A. Coillet2, B. Cluzel2 and P. Noé1 1 Univ. Grenoble Alpes, CEA, LETI, F-38000 Grenoble, France. 2 ICB, UMR CNRS 5209, Université de Bourgogne Franche Comté, 21078 Dijon cedex, France 3 CESAM-Physics of Solids Interfaces and Nanostructures, B5, Université de Liège, Belgium. 4 Univ. Grenoble Alpes, CEA, INAC, F-38000 Grenoble, France. 5 CNR-IOM-OGG c/o ESRF – The European Synchrotron, F-38043 Grenoble, France.	Amorphous chalcogenide thin films for nonlinear integrated optics in mid-infrared
	Glukhov I.A., Moiseev S.G., Dadoenkova Yu.S., Bentivegna F.F.L. 1 Lab-STICC (UMR 6285), CNRS, ENIB, CS 73862, Brest Cedex 3, France 29238 2 Ulyanovsk State University, 42 Leo Tolstoy str., Ulyanovsk, Russia 432017 3 Kotelnikov Institute of Radio Engineering and Electronics of the Russian Academy of Sciences, Ulyanovsk Branch, 48/2 Goncharov Str., Russia 432011 4 Ulyanovsk State Technical University, 32 Severny Venetz str., Ulyanovsk, Russia 432027	Polarization-selective defect mode suppression in a deterministic aperiodic photonic crystal through plasmon excitation in an embedded array of metallic nanoparticles
	W.A.P.M. Hendriks, M. Dijkstra, C.I. van Emmerik, I. Hegeman S.M. Garcia-Blanco MESA+ Institute, University of Twente, P.O. Box 217, 7550 AE, Enschede, The Netherlands	High refractive index low-loss aluminium oxide waveguides
	Zhengkai Jia1, Hua Yang2, Hui Wang1, Xing Dai1, Alison H. Perrott1,2, Frank H. Peters1,3 1 Integrated Photonics Groups, Tyndall National Institute, Cork, Ireland. 2Rockley Photonics Ireland, Cork, Ireland 3 Department of Physics, University College Cork, Cork, Ireland.	Quantum Well Intermixing of InP-Based AlInGaAs Quantum Wells Using IFVD Technique and the Mask Boundary Effect
	I.V. Kondratyev 1, M. Yu. Saygin 1, I. V. Dyakonov 1, S. S. Straupe 1, S. P. Kulik 1 1 MSU Quantum Technology Centre, Leninskie gory 1, building 35, 119991, Moscow, Russia.	Robust Architecture for Programmable Universal Unitaries
	S.M. Kostritskii1, Yu.N.Korkishko1, V.A. Fedorov1, O.G. Sevostyanov2, I.M. Chirkova2, E. Kokanyan3, M. Aillerie4 1RPC Optolink, Zelenograd, Sosnovaya al. 6A, 124489, Moscow, Russia 2Institute of Basic Sciences, 650000, Kemerovo, Russia 3Institute for Physical Research, Ashtarak-2, Armenia 4Centrale Supelec, LMOPS, University of Lorraine, Metz, France	Phase composition and electro-optic properties of channel proton-exchanged LiNbO3waveguides
	Habib Mohamad 1, Sylvain Blaize 2, Alain Morand 1, Pierre Benech1 1IMEP-LAHC, CNRS, Grenoble-INP, Institute of Engineering Univ. Grenoble Alpes, 38000 Grenoble, France. 2 L2n, Universite´ de Technologie de Troyes, 12 rue Marie Curie CS 42060 10004 Troyes Cedex, France.	The Aperiodic DM-FFF compared to the A-FMM: A Rigorous Method for the Modeling of Guided Optical Structures
	Paramita Pal1*, E. Kumi Barimah1, Benjamin Dawson2 and Gin Jose1 1*School of chemical and process engineering, University of Leeds, LS2 9JT, UK	Er3+ doped Silica-on-Silicon using fs-laser doping process for Integrated Waveguide Amplifier Platforms
	Vincent Pelgrin1,2, Yuchen Wang2, Carlos Ramos1, Laurent Vivien1, Zhipei Sun2, Eric Cassan1 1Universite´ Paris-Saclay, CNRS, Centre de Nanosciences et de Nanotechnologies, 91120, Palaiseau, France 2 Department of Electronics and Nanoengineering, Aalto University, P.O. Box 13500, FI-00076 Aalto, Finland	Kerr effect enhancement through hybrid integration of 2D materials on the silicon platform
	R.Peyton 1, 2, D. Presti 1, 2, F. Videla 1 and G.A. Torchia 1, 2 1 Centro de Investigaciones Opticas (CONICET-CIC-UNLP) Camino Centenario y 506, s/n, M.B. Gonnet (1897),Buenos Aires, Argentina 2 Departamento de Ciencia y Tecnolog´ia, Universidad Nacional de Quilmes, Roque Saenz Pen˜a 352, Bernal (1876), Buenos Aires, Argentina	Multi Mode Interferometer plus simplified coherent coupling to design a small footprint SOI power splitter
	Dura Shahwar, Matteo Cherchi, Mikko Harjanne, and Timo Aalto VTT Technical Research Centre of Finland	Polarization splitter based on form birefringence for micron-scale Silicon photonics
	Kang Wang Universite´ Paris-Saclay, CNRS, Laboratoire de Physique des Solides, 91405, Orsay, France	Valley-polarized beam propagation in metallic photonic graphene