The team of master's, Ph.D. and post-doctoral researchers at the Centre for Broadband Communications, Nelson Mandela University, South Africa.

Courtesy of T. Gibbon

Optics in Africa: Six Stories

Stewart Wills

A recently published JOSA A and B feature issue highlighted the wide-ranging optical and photonic research being pursued by scientists on the African continent. For this first installment of a two-part feature, OPN talked with several of the contributors.

In October 2020, the OSA journals JOSA A and JOSA B published a virtual joint feature issue, *Optics in Africa* (www.osapublishing.org/josaa/virtual_issue.cfm?vid=476). According to the issue's editors—OSA Fellow **Andrew Forbes** and OSA member **Angela Dudley** (South Africa), OSA Ambassador **Rim Cherif** (Tunisia), and **Alain M. Dikande** (Cameroon)—the project sought to highlight, in a collection of 59 original research papers, review articles and tutorials, the "scope of research on the continent and its international context." The issue also shone the spotlight on a new generation of researchers in Africa, and the opportunities and challenges they face in moving African optics and photonics research forward.

For a different angle on this area, OPN talked with six of the issue's contributors, to get their personal perspectives on their work, and on photonics research and education in their home countries. In this first installment of a two-part article, we look at their stories and the wide array of research areas they're exploring. The second installment, in an upcoming issue, will recount some of their observations on the state of science in Africa, both in their home countries and the larger continent.

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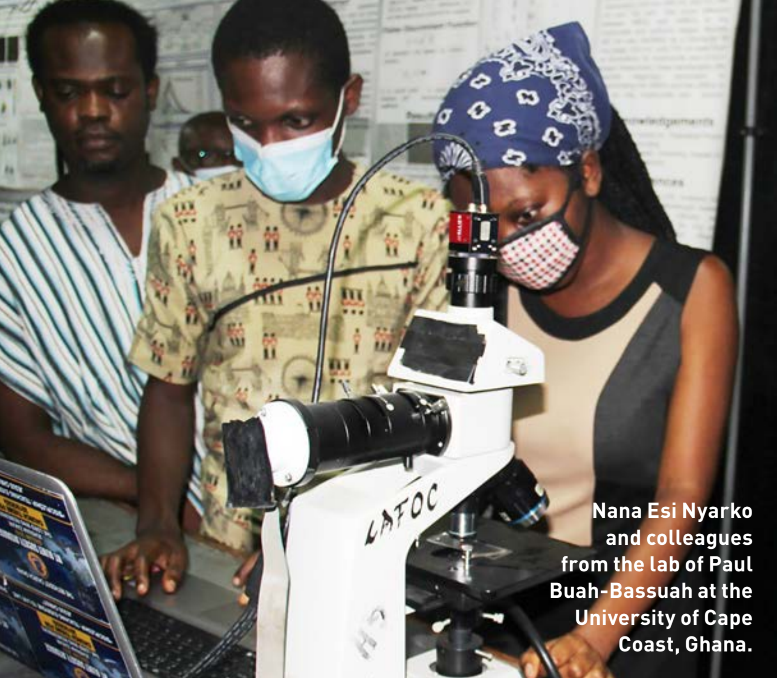


Nana Esi Nyarko and colleagues from the lab of Paul Buah-Bassuah at the University of Cape Coast, Ghana.

Courtesy of P. Buah-Bassuah

Putting laser-induced fluorescence to work

Two of the researchers that OPN spoke with—**Paul Buah-Bassuah** of the University of Cape Coast, Ghana, and **Timoleon Crepin Kofane** of the Université de Yaoundé I, Cameroon, and the Botswana International University of Science and Technology (BIUST), Botswana—are veterans of African science, having spent decades building successful optics and photonics labs and academic links on the continent. The career trajectories for both, however, got their start during the 1980s in Europe.

For Buah-Bassuah, the catalyst was a program at the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste, Italy, which he attended in the mid-1980s while a physics grad student at the University of Cape Coast. "That was the first time I was introduced to lasers," he says. With the encouragement of his ICTP mentor, the late Tito Arrechi, and the sponsorship of another ICTP scientist, Gallieno Denardo, Buah-Bassuah spent the next four years at the University of Florence, earning a Ph.D. using lasers to study droplets in miscible fluids.

The ICTP link also proved helpful to Buah-Bassuah when he returned, in the late 1980s, to the University of Cape Coast, with an eye toward starting up his own lab in Ghana. With the help of Denardo and several others, a team of renowned Ghanian scientists investigated the feasibility of creating a laser and fiber optics lab at the university under Buah-Bassuah's leadership.

"Initially there were a lot of doubts," he says now. One reason was the size and complexity of the lasers typical at that time. "Most of the heavy lasers used water flow to control temperature and bring down heat," Buah-Bassuah explains, and concerns were raised about the ability to ensure a constant flow of water. He instead decided to center the lab's work around small diode lasers used for diagnostics and other purposes, and secured funding for a stint at Lund University in Sweden to learn to make such lasers. "It was very, very useful to start from there," he says, as the plan enabled him to acquire the necessary funding to start a "small-budget laboratory" and build a Ph.D. program.

In the intervening decades, Buah-Bassuah's lab has been a productive platform for science, creating dozens of M. Phil. and Ph.D. recipients and a steady stream of new discoveries. One focus has been applying laser-induced fluorescence to a wide variety of problems in health, environment and agriculture—everything from an early study on insect-resistant cowpeas, in partnership with the university's agriculture department, to work on cataract lenses and antimalarial plant species, the subject of his team's two papers in the recent JOSA feature issue. An interesting new research direction for the lab is putting lasers and microscopes together to efficiently count malaria parasites in laboratory samples—a potentially important enabler for better antimalarial research.

Throughout his career, Buah-Bassuah says, his team has benefited from the lab's significant efforts to forge international collaborations and partnerships, not just with overseas partners but on the African continent. The latter have included initiatives in fiber optics with

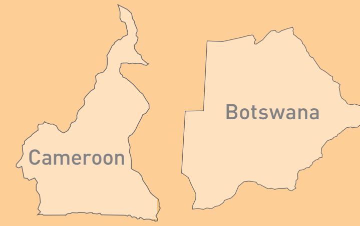
"I'm very proud that I'm among the pioneers to bring lasers to Africa."

—Paul Buah-Bassuah, University of Cape Coast, Ghana

Courtesy of P. Buah--Bassuah

Courtesy of T.C. Kofane

> “In reality, all phenomena in nature are nonlinear.”
>
> *—Timoleon Crepin Kofane, Université de Yaoundé I, Cameroon; BIUST, Botswana*



universities in South Africa; efforts in biology, chemistry and other areas with the Kwame Nkrumah University of Science and Technology in Ghana; and work to set up optics laboratories in several other countries, to help raise awareness of “the relevance of laser research on the continent.”

Buah-Bassuah’s focus on lasers and international connections came together in an especially meaningful way in 2012, when he led a delegation representing four countries—Ghana, Mexico, Russia and New Zealand—to officially introduce, at UNESCO, the proposal for an International Year of Light, which came to fruition in 2015. While he notes that the IYL effort, championed and led particularly by OSA Fellow John Dudley, had many contributors, he believes that his role doing laser physics in a small African country, and showing the practical benefit that light science could offer there, helped to make a uniquely compelling case. “I’m very proud,” he says, “that I’m among the pioneers to bring lasers to Africa.”

Thriving with chaos

Another veteran scientist in sub-Saharan Africa, T.C. Kofane, earned his Ph.D. in physics at the University of Burgundy, France, in 1987, and returned to his native Cameroon a year later to begin work as a senior lecturer at the University of Yaoundé. Since then, he and the research group he has built have worked on an unusually diverse set of research themes centered around nonlinear dynamics and chaos—exploring everything from optical fiber to biophysics to black holes.

“In reality, all phenomena in nature are nonlinear,” says Kofane. Exploring how nonlinear effects balance the material effects of dispersion and diffraction led him in particular to investigate the physics of solitons—ultrashort, few-cycle optical pulses that can travel along optical fiber and other media, conserving their energy and preserving their shape. The team was able to model the behavior of these dissipative “light bullets” in erbium-doped optical fiber, to show how their wave equation could be derived and solved.

In the JOSA feature issue, Kofane and collaborators reviewed the contribution of African scientists in this area, in a paper titled “From African ‘tam-tam’ to nonlinear optics.” While the work sounds arcane, Kofane notes that it has practical applications in, for example, optimizing information flow in fiber-based networks.

“Don’t forget that those who are doing applications need also to understand all physical mechanisms that are behind the few-cycle regime,” he points out. “What we mainly do—for optical fiber, for metamaterials, for Bose-Einstein condensates, for lasers—is to provide a certain theoretical reference for the development of optical instruments, based on enhanced models, with applications in data transmission and processing and manipultion of nano-objects using light beams, among others.”

Kofane’s work on solitons has also taken his research into the related area of modulation instabilities, the study of how small periodic perturbations in amplitude or phase can be chaotically amplified to create trains of solitons. These instabilities have applications in fiber and supercontinuum generation—but also in the concept of “rogue waves” on the ocean and in a range of other applications (see “Rogue Waves of Light,” OPN, November 2015, p. 34). “Modulation instabilities are studied in all areas,” Kofane says. “You can see them in Bose-Einstein condensates, plasma physics, DNA—everywhere where you can find dispersion and nonlinearity.”

Like Paul Buah-Bassuah, Kofane says his research has benefited from his ongoing efforts to forge international collaborations and connections. In Europe, he has served as a senior scientist at ICTP in Trieste, and had a long association as a visiting professor at the Max Planck Institute of Complex Systems in Dresden. On the African continent he has established collaborations

Dismas Choge numerically models laser emissions from nonlinear crystals.

Courtesy of D. Choge

with research groups in the Republic of Gabon, Nigeria, South Africa and elsewhere.

Of particular satisfaction has been his recent association as a visiting professor with BIUST, the second-largest university in Botswana—and one that enrolled its first class about ten years ago this past March. "It is a young group, and it's growing," he says, adding that the school has taken pains to attract professors from around the world for its international establishment.

"Botswana is an ambitious country," Kofane observes. "The government's dream is to be like Switzerland in Europe—'We are small, but we master technology.' That is the vision here." He sees considerable interdisciplinary energy and drive at BIUST, which he believes could soon "be ranked as one of the best universities in Africa."

Eyeing new light sources

OPN also talked with two younger scientists in sub-Saharan Africa who contributed papers to the JOSA feature issue, and who are working to build research operations in their own home countries. Like Buah-Bassuah and Kofane, these two researchers got their start in institutions outside of the African continent. But for both of them, the launch pad for their research careers was not in Europe, but in China.

Dismas Choge currently works as a faculty member at the University of Eldoret, in Eldoret, Kenya, a campus that's focused on basic and applied sciences and that lies about 350 km northwest of Nairobi. He started work there a half-decade ago as a tutorial fellow, after finishing up a master's degree, and had been working at the university a short time when an opportunity opened up to pursue a Ph.D. with the research group of Liang Wan-guo at the Chinese Academy of Sciences in Fuzhou.

Choge jumped at the chance, and spent a number of years studying the polarization of light in an emerging photonic material, periodically poled lithium niobate (PPLN), that's seen as an increasingly interesting candidate for integrated photonics. "I got so fascinated by this work" while in China, Choge recalls, "and I took it up."

He is especially fascinated by PPLN's capabilities for generating light at different visible wavelengths from the same pump source, through nonlinear wavelength-conversion techniques. While in China, Choge helped develop an all-solid-state setup that used a single PPLN crystal, along with sum-frequency generation and second-harmonic generation, to create a light source that simultaneously lased at blue and orange wavelength bands that are important for applications in biomedical optics and beyond.

After completing his Ph.D. and returning to the University of Eldoret, Choge has continued his efforts to push forward the wavelength-conversion possibilities of the PPLN system. While he had done both experimental and theoretical work on the system in China, upon returning to Eldoret he switched to theoretical work, owing to resource constraints on lab equipment and scientific infrastructure—a common pattern, according to Choge and others we spoke with, for scientists in a number of sub-Saharan African countries.

"In grad schoool I was introduced to the field of crystal optics, and encouraged to work on PPLN ... I got so fascinated by this work, and I took it up."

—Dismas Choge, University of Eldoret, Eldoret, Kenya

Courtesy of D. Choge

Courtesy of T. Gebremariam

> "Our university is happy to share, and to invite people to be associated, to realize this kind of collaboration."
>
> *—Tesfay Gebremariam, Arba Minch University, Arba Minch, Ethiopia*

In the paper he coauthored for the JOSA feature issue, he showed numerically how PPLN crystals could be coaxed to simultaneously generate visible light of five different colors, spanning wavelengths from violet to orange, from a single 980-nm pump source. The result—which he hopes can soon be realized experimentally—holds promise, according to the paper, for applications in biomedicine, optical data storage, visible-light communications and more.

Looking ahead, Choge says he's excited about the prospects for introducing his students to the PPLN system's potential in integrated-photonics devices such as micro-ring resonators and modulators. "Maybe, in the near future, we can put together these devices on a single crystal," he says, "and see what we're able to do with that."

Modeling quantum entanglement

The early career trajectory of another scientist on the continent, **Tesfay Gebremariam** of Ethiopia, was remarkably similar to that of Choge. Building on what he says was a long-standing interest in physics—"since I was in grade 9"—he obtained a B.S. in physics from Haramaya University in Ethiopia in 2006 and an M.S. from Addis Ababa University in 2010. He then went to work as a lecturer at Arba Minch University in Arba Minch, Ethiopia. Three years later, he joined a Ph.D. program with the research group of Li Chong at the Dalian University of Technology in China—where he began to explore the exotic world of quantum optics.

While in China, Gebremariam helped to develop the theory for a two-cavity quantum optical diode to facilitate the one-way transmission of photons—an important device for control systems in emerging quantum information setups. He also dug deeply into the theory behind cavity-based quantum optomechanical systems. The interaction between light and matter in such systems, he says, has a variety of potential applications in quantum information, as well as in other areas such as extremely high-sensitivity quantum force sensing and measurement schemes.

Upon wrapping up his Ph.D. in China—a stint that included the opportunity to publish a number of papers and present his work at more than nine scientific conferences—he returned to Arba Minch University in 2018 as an assistant professor, where he has established a Ph.D. program. He has also continued his work modeling quantum optomechanical systems, publishing more than seven papers in 2020.

In his recent paper in the JOSA feature issue, Gebremariam numerically explored the potential for bipartite entanglement and correlations between the optical and mechanical parts of a two-cavity, hybrid optomechanical array including an oscillating mirror at one end. His work established the possibility of quantum entanglement and information transfer between the optical and mechanical modes in the model. That suggests that a physical system based on the model, applied to 2D optomechanical crystals, could be a promising candidate for preparing remote entangled quantum states in information processing.

When asked whether he's seeking, and interested in, new international collaborations on this work, Gebremariam's response is "Completely, 100% yes." He says that he has been forging interdisciplinary research and teaching partnerships within Arba Minch University, and has also begun new collaborations with other institutions within Ethiopia, such as Jimma University, the Adama University of Science and Technology and Wolkite University. He also notes that both he and his university are interested in creating bilateral teaching and research arrangements with international institutions both inside and outside of Africa. "Our university is happy to share," he says, "and to invite people to be associated, to realize this kind of collaboration."

Michelle Ngugi, a CBC researcher, developing an optical-fiber sensor for renewable-energy wind turbines.

Courtesy of T. Gibbon

Questions of timing

The stories recounted thus far demonstrate the wide variety of research being pursued by optical scientists in a number of countries in sub-Saharan Africa. Still, the editors of the recent JOSA feature issue admit that the decades of turmoil of the post-colonial period have "seen African optical science dither," and that the tiny fraction of the world's research output produced on the continent tends to be "dominated by North African countries and South Africa." We close this brief account with a look at the work of two other researchers from those areas.

Initially attracted, as an undergraduate, to teaching, **Tim Gibbon**, in South Africa, caught the fiber optics research bug in a master's program where he worked on measuring dispersion effects in optical fiber. He went on to pursue a Ph.D. at Nelson Mandela University (NMU)—a school with 30,000 students, located in Port Elizabeth, in the rural Eastern Cape region of South Africa—followed by a postdoc at the Technical University of Denmark from 2008 to 2010. Thereafter he returned to South Africa to join the faculty at NMU, where he now directs the school's Centre for Broadband Communications (CBC).

The CBC's focus on fiber and communications has Gibbon and his students studying myriad problems, some addressing familiar telecom priorities and others ranging farther afield. An example of the latter—and the subject of one of five papers coauthored by Gibbon in the recent JOSA feature issue—are efforts supporting the Square Kilometer Array (SKA), the joint effort by a global consortium including South Africa, Australia and the United Kingdom to build a huge, distributed network of radio telescopes with a total collecting area of approximately 1 km^2. The hundreds of far-flung radio telescopes in the array will be linked by optical fiber to a supercomputer tasked with crunching the huge volumes of data.

Such a system, Gibbon notes, requires the distribution of extremely stable clock signals—to the picosecond stability range—between the central station and the telescope, to keep the flow of geographically dispersed data in sync. So Gibbon and his students have been researching all-optical approaches for creating fiber-based time-and-frequency reference networks. These, he points out, also have relevance for areas far removed from astronomy, such as high-frequency stock trading, where microsecond or faster differences can dramatically impact share prices. "The kind of time work we're doing is pivotal not just to a big science project like the SKA, but to banking, industry—any kind of endeavor," he says.

Other papers in the JOSA feature issue explore aspects of fiber-based time-and-frequency networks and clock signals for applications from satellite-based GPS to emerging 5G communications for self-driving vehicles. In still other work, the CBC is exploring the concept of fiber-to-the-home (FTTH) in an African context, and the types of distributed network topologies needed to connect villages for Africa's dispersed, largely rural population—what Gibbon's team calls fiber-to-the-hut. "It's still FTTH," says Gibbon, "but it's an example of how Africa needs to make its own flavor of these technologies."

"Optics is such a beautiful topic … It's like a wonderful gym for your mind."

—Tim Gibbon, Nelson Mandela University, South Africa

Courtesy of T. Gibbon

Courtesy of S. Chabou

> “I chose the Institute of Optics and Precision Mechanics at the University of Setif because of my passion for physics.”
>
> *—Saoussene Chabou, University of Setif, Algeria*

The CBC also has active projects across other domains touched by fiber optics and communications—everything from efforts to enable data links with underwater robots and drones, to the creation of optically based acoustic sensors for seismology and other geophysics. The Ph.D. students in the program are similarly diverse, drawn not just from South Africa but from a variety of other sub-Saharan countries.

An important part of the CBC’s mission, according to Gibbon, is helping students learn how to innovate—to think about entrepreneurship and business priorities, about spotting a problem and the opportunity to solve it. For Gibbon, optics—with its combination of simulations, analytical thinking, experiment and fieldwork—is a perfect tool for achieving those goals. “It’s such a beautiful topic,” he says. “It’s like a wonderful gym for your mind.”

Starting out in structured light

We began this collection of six stories with a scientist with decades of experience doing research on the African continent. We end with someone just starting out her research career.

Since 2010, **Saoussene Chabou** has pursued what she calls “a passion for physics” at the Institute of Optics and Precision Mechanics of the University of Setif in western Algeria. After receiving a bachelor’s degree from the institute in 2013 and a master’s in 2015, she passed a national qualifying exam and began her Ph.D. studies in 2016. As this feature was being written, she was gearing up for her thesis defense.

Chabou’s Ph.D. work (and the subject of two papers coauthored by her in the JOSA feature issue) has centered around structured light—the use of diffractive optical elements and other tools for precision shaping of light beams (see “Structured Light: Tailored for Purpose,” OPN, June 2020, p. 24). She was introduced to the topic by her faculty advisor at the university, Abdelhalim Bencheikh, as a final project for her master’s, and continued to pursue it in her doctoral study.

She has focused in particular on numerical modeling of certain classes of “pseudo-non-diffracting beams,” which are resistant to spreading as they propagate. The best-known such beams are Bessel beams, but Chabou’s studies have involved several other intriguing alternatives, including Laguerre-Gauss (LG) and cosine-Gauss (CG) beams.

The research team’s work has explored the nondiffracting properties of both kinds of beams, and especially their ability to “self-heal”—that is, to recover or reconstruct properties such as amplitude, phase, or angular momentum—after encountering an obstacle. The work could have implications for the propagation of laser beams through obstacles, and for specific applications in areas as far-flung as optical particle manipulation, imaging and light-sheet microscopy. Chabou says the team is following up its numerical efforts with collaborations to test the models, including work with OSA Fellow Andrew Forbes’ lab at the University of the Witwatersrand in South Africa and OSA Fellow Cornelia Denz’s lab at the University of Münster in Germany.

Like most persons pursuing doctoral study, Chabou has found the road made a bit rockier by COVID-19, which temporarily closed schools and universities, forced a transition to distance-learning platforms and created logistical problems and laboratory access restrictions. But she was able to adapt to distance education and research, with regular Zoom meetings with her supervisor to ensure that things have stayed on track.

When Chabou soon completes her Ph.D. defense, she will enter the academic job market, and—like the other five scientists profiled here—will continue contributing to the future of African science. But what does “African science” really mean? What challenges and opportunities are common to doing science in the continent’s diverse societies? In the second installment of this two-part feature, in a future issue, we’ll explore the perspective of these six African researchers on these and other questions. OPN

Stewart Wills is the senior editor of OPN.