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Self-Mixing Interferometry for Industrial Applications

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This special section of *Optical Engineering* is devoted to recent advances in self-mixing interferometry (SMI), with special emphasis on industrial applications.

Self-mixing interferometry, also variously called feedback interferometry, or injection interferometry, or induced modulation, dates back to 1968 when Rudd observed, in a HeNe laser perturbed by the optical backscattering from the remote target, that the small ripple of power of the amplitude modulation was serendipitously carrying the interferometric waveform of a target vibration. Later in 1977, one of the authors was able to develop a full displacement-measuring interferometer based on SMI, exploiting both amplitude (AM) and frequency (FM) modulations in a dual-mode Zeeman He-Ne laser, and able to resolve the displacement in $\lambda/8 = 79$-nm steps on a dynamic range up to 2 m. Yet, working with a source HeNe laser, of bulky size and HV-bias requirement, prevented the SMI from becoming a real contender to the already established and very successful "laser interferometer" based on a traditional external Michelson configuration and introduced by Hewlett Packard for the machine-tool metrology. So, for more than ten years, SMI was confined to nothing more than a scientific curiosity.

Meanwhile, in 1980, Lang and Kobayashi introduced their well-known equations describing optical feedback in a semiconductor laser, thus providing a firm theoretical background for understanding self-mix interaction as well as optical chaos phenomena. Laser diodes meanwhile progressed a lot, becoming reliable and low-cost sources with clean single-mode emission. So, times were ripe in 1990 for the introduction of the laser diode as the source of SMI, gaining the big advantage of compact size and low power requirement and, not less important, entering into the new regime of intermediate feedback level operation, one capable of unambiguous displacement $\lambda/8$ count with just the AM signal and without phase unwrapping. On the other hand, the limitation of 3-digit accuracy of diode lasers, relative to the 7-digit accuracy of a frequency-stabilized HeNe, shaped the SMI laser diode instrument as complementary to the HeNe, the former for industrial applications and the latter undisputed for metrology.

In addition to displacements, many new applications soon flourished, like the measurement of velocity, vibration waveforms, optical echoes, absolute distance, and fluid flow measurement. Also, it was understood that, looking at the dependence of self-mixing signals from physical parameters, we can introduce new methods for the measurement of linewidth and alpha factor in laser diodes. The international impact of these papers is well documented by the over 2,500 papers published on the subject from 1994 to 2010.

Another big application has been the characterization of MEMS structures by SMI, a unique noncontact noninvasive method, soon developed into the differential-channel vibrometer, capable of measuring the mechanical transfer function and detecting the mechanical hysteresis cycle of micro- and macrostructures.

Recent contributions include the analysis of speckle-pattern errors in SMI measurements on rough surfaces, and the measurements of thickness, curvature, and angles. Also noteworthy, SMI has proven quite successful as a mechanism of detection at the boundary of far-infrared and microwaves, namely as a terahertz waves remote echo detector.

In conclusion, we can say that nowadays self-mixing is for sure a mature technique, not only scientifically but also well demonstrated in viable industrial products for a variety of applications. Over the past several years, the field of self-mixing interferometry has been focused on the scientific challenges of industrial and consumer applications, as well as of biomedical signal sensing. The papers in this special section address several of these remaining challenges to the employment of self-mixing interferometry and recent advances in the technology. It begins with a review article that summarizes past developments, including some of the major developments mentioned in this editorial, as well as more current research.

Silvano Donati earned his doctorate in physics (Laurea in Fisica) *cum laude* from University of Milan, Italy, 1966, and has been chair professor of University of Pavia from 1980 to 2010, and lecturer from 2010 to 2014 before becoming emeritus professor in 2015. He has authored or co-authored 330+ papers and holds a dozen patents. He has been invited as a visiting professor at several Universities of Taiwan: NTU, Taipei, 2005, Sun Yat Sen, Kaohsiung (2007, 2008, 2010), NCKU, Tainan 2012, NCHU, Taichung, 2013-14, NTUT, Taipei 2015-6, and is currently a visiting researcher at NTU (Taipei). He is lifetime member of SPIE, life fellow of the IEEE, and OSA emeritus fellow.

Michele Norgia received the MS degree with honors in electronics engineering from the University of Pavia in 1996, and in 2000 he received the PhD degree in electronics engineering and computer science. In 2006, he joined the Electronic and Information Science Department of the Politecnico di Milano, where he is now a full professor. His main research interests are optical and electronic measurements, interferometry, chaos in lasers, micro-electro-mechanical sensors and biomedical measurements. He is author of more than 150 papers published in international journals or conference proceedings. He is a member of the Italian Association “Group of Electrical and Electronic Measurements” and a senior member of IEEE.