F. Morichetti

Spotlight on "Broadband Mid-Infrared Frequency Comb Generation in a Si_3N_4 Microresonator"

https://www.osapublishing.org/spotlight/summary.cfm?id=331311

Published in Optics Letters, Vol. 40, No. 21, pp. 4823-4826 (2015)

by Kevin Luke, Yoshitomo Okawachi, Michael Lamont, Alexander Gaeta, and Michal Lipson

Spotlight summary:

No more than four years ago, a broadband integrated frequency comb generator operating in the near-infrared range was highlighted in Spotlight on Optics. (https://www.osapublishing.org/spotlight/summary.cfm?id=220223). At that time, the realization of an entire device on a photonic chip set a first milestone towards what we called the "comb generator dream" of extremely compact, cheap and robust optical comb generators. A promising step forward compared to traditional technologies exploiting ultrafast mode-locked lasers, which definitely work very well, but suffer from bulkiness, cost and limited line-separation issues.

Since then, optical comb generators have become even more attractive for many applications, such as optical clocks, precision frequency metrology, high-speed communications systems and optical waveform synthesizers. One of the next frontiers is now moving deeply into the mid-infrared range, where the advent of optical comb generators is expected to bring new tools for advanced precision spectroscopy, molecular structure investigation and gas sensing.

Four years later, we are here to comment on another milestone in the optical comb generator route. The same material as before, that is silicon nitride (Si_3N_4). And the same research group, joining the teams of M. Lipson and A. Gaeta from Cornell University. Yet, much longer wavelengths now, well above 2 μm. And a completely new story begins.

Unfortunately for people working in integrated optics, moving from a wavelength range to another is not a copy-and-paste process, even when dealing with passive devices. Not only material properties may change dramatically, but the behaviour of materials commonly used at certain wavelengths can be almost unknown at others, because of the lack of characterization instruments or even light sources. And this is the case of Si_3N_4, whose optical properties have been deeply studied at telecom wavelengths and below, but not in the mid-infrared range.

For a reliable description of the optical properties of Si_3N_4 in the mid-infrared range, K. Luke and co-workers first derived a wavelength extended version of the Sellmeier equation. They achieved it by characterizing the refractive index and the absorption coefficient of the material over an ultra-broad wavelength range, spanning from the ultraviolet (193 nm) up to the far infrared (33 μm). Their results demonstrate that Si_3N_4 can provide strong enough anomalous dispersion to generate wide spectral combs in the near-infrared range, yet requiring an optical waveguide with a height (about 1 μm) well beyond the thicknesses typically limited by the intrinsic film stress. To overcome the mechanical stress limit, a technique previously developed by the same group was employed, that is based on crack isolation trenches realized before Si_3N_4 film deposition. Further, to prevent stress-induced wafer bowing, both sides of the wafers were processed.

However, this was not enough. Loss was actually the key issue to address, because efficient resonator-based comb generators require very high Q-factors. In order to minimize absorption losses in the film, multiple annealing steps were performed during film deposition. This techniques allowed to increase the Q-factor of a microring resonator from a value of 55,000, that was measured on a reference single anneal device, to a record Q value of 1.0×10^6 at a wavelength of 2.6 μm, this being the highest Q ever achieved for on-chip resonators operating in this wavelength range. The authors claim also that the Q factor could be even improved with optimized etching process and improved anneal cycling during Si_3N_4 deposition.

After reading this paper, one can't help thinking about the next episode of the integrated comb generator saga. It is difficult to predict how the story will evolve, if even longer wavelengths will be covered with Si_3N_4 comb sources, or other materials will come into play. Let's hope to have news soon, hopefully before the next four years.

Francesco Morichetti