F. Morichetti

Spotlight on "Second-harmonic generation of light at 245 nm in a lithium tetraborate whispering gallery resonator"

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by Josef U. Fürst, Karsten Buse, Ingo Breunig, Petra Becker, Josef Liebertz, and Ladislav Bohatý

Spotlight summary:

Switching the light on at any wavelength, easily and efficiently, is not an easy game. This is indeed one of the main issues people working in optics have to face, because a general-purpose recipe to build light sources does not exist. And realistically speaking, probably it will never be found.

Light sources are like *haute couisine* dishes, whose preparation needs to be accurately tailored to fulfil specific tastes and different requirements. The choice of material compounds is of primary importance, since high optical gain or large nonlinear response is required for light generation and manipulation at the desired wavelength. Yet, good ingredients are not always available. At certain wavelengths, no materials seem to offer sufficient efficiency to generate light. In these cases, scientists are asked to operate like master chefs capable to transform apparently poor and flavourless ingredients into special food.

For example, light generation is a challenging task in the short/mid ultraviolet range, where most optical materials exhibit poor transparency. A way to realize it exploits second-harmonic generation (SHG) in borate crystals, which are nonlinear materials with a transparency range that can spread deeply into the ultraviolet. Among these materials, lithium tetraborate ($Li_2B_4O_7$) is particularly promising because the phase-matching wavelength (that is the wavelength at which SHG efficiency is maximum) is close to the blue emission line of argon-ion lasers (488 nm), around which many applications have been established; moreover the UV wavelength of the harmonic light (244 nm) lies within the transparency window of the crystal. Nonetheless, the potential of $Li_2B_4O_7$ as a crystal for SHG-mediated UV light generation has never been fully exploited due to its small nonlinear-optical coefficient. A classical powerful strategy to increase the conversion efficiency of weakly nonlinear materials makes use of resonant devices, such as whispering gallery resonators (WGRs), inside which any nonlinear interaction can be dramatically boosted. Though simple on paper, high efficiency cavity-enhanced SHG in the UV range requires a master touch to be achieved in real life.

This is indeed what Fürst and collaborators have done in their work. By exploiting resonant-enhanced SHG in an engineered WGR geometry, a conversion efficiency of more than 2% has been reached using 490-nm laser pump sources with a few milliwatts of output powers. To give an idea, this means more than twenty-times efficiency improvement compared to previous results, at a thousand times lower pump power.

No secret ingredients anywhere, just a careful optimization of the device design and fabrication technique. A millimetre-sized WGR was fabricated from a bulk $Li_2B_4O_7$ single crystal that was mechanically machined to a spheroid and accurately polished to minimize surface roughness. In this way ultra-low loss was achieved in the WGR, that is comparable to those of the bulk crystal (extinction coefficient of 0.1 m^{-1} at 490 nm), enabling to reach a quality factor as high as $2x10^8$. Since the efficiency of cavity-enhanced SHG scales with the third power of the quality factor, it is easy to realize where such a high conversion efficiency comes from. To optimize the phase matching condition (that is strongly dependent on temperature), the WGR was thermally stabilized on a millikelvin scale to compensate against thermal instability caused by pump light absorption. A route to further improve the conversion efficiency is also identified, that exploits an active locking technique to reduce the effect of thermal instability, and the identification and exploitation of the whispering gallery modes with the smallest effective volume.

Although the optical spectrum is becoming populated with many kinds of light sources, optics is still hungry for new solutions to realize more and more compact and efficient lasers. This work clearly shows that research has to be carried out on a two-fold path. On the one hand, looking for novel material compounds as new ingredients; on the other hand, developing novel device concepts and fabrication techniques to boost the efficiency of materials that are already in use. In other words, devices are the recipes to enhance the flavours of our ingredients. Let’s keep in mind that we have to make a good choice on both sides...

Francesco Morichetti