Spectral holes in time representation—from ultrafast pulse shaping to time-space holography

Peeter Saari*

Institute of Physics, University of Tartu
**peeter.saari@ut.ee*

Burning a hole into the absorption spectrum of a piece of material subject to photochemical or photophysical spectral hole burning (SHB) does not just mean creating a narrow peak in the slab's transmittance spectrum. In the spectral region of the hole, a peculiarity in the frequency dependence of the refractive index arises inevitably as well. The profile of the peculiarity is determined by the Hilbert transform of the shape of the hole, and it shifts the phases of the Fourier constituents of the incident light pulse in order to ensure the causality of the time response of the slab. This is shortly the theoretical background of SHB pulse shapers, invented at the Institute of Physics in Tartu at the end of 1980s.[1,2]

Like any photosensitive material, SHB material cannot record phase distributions of the incident light signal. However, by combining the treatment of the impulse response of a slab subject to SHB and a time version of the "holographist's formula" by involving a reference pulse, we succeeded to develop in Tartu the so-called time-domain holography—recording a pulsed light signal of any complex shape and of duration up to nanoseconds, and playing it back several hours later with a sub-picosecond resolution.[3,4] In subsequent publications, time-domain holography was joined with common spatial-domain holography, and by additionally making use of the polarization sensitivity of PHB materials, a complete recording and play-back, as well as phase conjugation of any ultrashort (within the femto-nanosecond range) light field (a scene), was worked out.[4-7]

Despite enormous information capacity of optical memories and processing speed of devices based on SHB materials, the need of cryogenic temperatures for their operation left them—as optical computing hardware in general—a loser in the competition with compact solid-state memory devices that were introduced in the 1990s. Nevertheless, the key concept of the time-domain holography—involving a reference pulse with known properties—proved fruitful in complete characterization of ultrashort pulses and impulse responses.[8,9]

References

1. H. Sõnajalg, A. Gorokhovskii, R. Kaarli, V. Palm, M. Rätsep and P. Saari, *Opt. Commun*., 1989, **71**, 377-380.
2. H. Sõnajalg, R. Kaarli P. Saari, *Journal de Physique IV*, 1991, **1**, 737-739.
3. A. Rebane, R. Kaarli, P. Saari, A. Anijalg and K. Timpmann, *Opt. Commun*., 1983, **47**, 173-176.
4. P. Saari, R. Kaarli and A. Rebane, *J. Opt. Soc. Amer. B*, 1986, **3**, 527-534.
5. R. Kaarli, P. M. Saari and H. R. Sõnajalg, *Opt. Comm*., 1988, **65**, 170-174.
6. P. Saari, in *Zero-Phonon Lines and Spectral Hole Burning in Spectroscopy and Photochemistry*, ed. O. Sild and K. Haller, Springer-Verlag, Berlin, 1988, pp. 123-142.
7. P. M. Saari, R. K. Kaarli, R. V. Sarapuu, and H. R. Sõnajalg, *J. Quantum Electr*., 1989, **25**, 339-345.
8. R. Trebino, R. Jafari, P. Piksarv, P. Bowlan, H. Valtna-Lukner, P. Saari, Z. Guang and G. Steinmeyer, in *Handbook of Laser Technology and Applications*, ed. C. Guo and S. Singh, Taylor & Francis, CRC Press, Boca Raton, 2021, pp. 487-537.
9. P. Piksarv, H. Valtna-Lukner, A. Valdmann, M. Lõhmus, R. Matt and P. Saari, *Opt. Express*, 2012, **20**, 17220-17229.