Novel Crystalline-Waveguide Broadband Light Sources for Interferometry

Markus Pollnau
Institute for Biomedical Imaging, Optics and Engineering
Swiss Federal Institute of Technology, CH-1015 Lausanne, Switzerland

In recent years, broadband fiber interferometers have become very popular as basic instruments used in optical low-coherence reflectometry for diagnostics of fiber and integrated optics devices or in optical coherence tomography (OCT) for imaging applications in the biomedical field. The longitudinal resolution of such instruments is inversely proportional to the optical bandwidth of the light source. Broadband luminescence from transition-metal-ion doped materials can significantly improve the longitudinal resolution compared to superluminescent diodes, but the low brightness of its luminescence typically leads to a low dynamic range in OCT. Femtosecond lasers based on, e.g., Ti:sapphire have, therefore, been used as large-bandwidth high-brightness light sources, and subcellular imaging has been demonstrated in this way. However, since current femtosecond light sources do not necessarily meet the requirements of compactness, ease of use, and low cost, a suitable light source for OCT is still not available.

Within the past two years, we have persued a novel approach toward compact broadband light sources for interferometry. Recently, the suitability of a superluminescent Ti:sapphire crystal as a light source in the spectral region 700-1000 nm for ultrahigh-resolution OCT with ~2 µm axial resolution has been demonstrated [1]. Guiding of the fluorescence in waveguide geometry can further increase the single-mode fluorescence output powers [2]. We have successfully created rib and ridge channel-waveguide structures from Ti:sapphire planar waveguides grown by pulsed laser deposition [3] by several different methods: ion-beam implantation and subsequent wet chemical etching [4], reactive ion etching [5], Ar-ion milling [6], and refractive-index variation by proton implantation employing either direct channel writing or in combination with polyimide strip-loading [7]. The maximum fluorescence output power of ~300 µW currently obtained from such channel-waveguide structures is sufficient for ultrahigh resolution OCT imaging at low speed for many applications. With further improvements in waveguide quality and coupling efficiency to a single-mode fiber, the usable fluorescence power is expected to further increase to the mW level. The significantly improved sensitivity that will result at this fluorescence power will allow for rapid *in vivo* ultrahigh-resolution OCT with a simple broadband light source.

Currently, we are investigating a novel approach using parallel channel waveguides as a light source for parallel OCT [8]. First results will be reported at the conference. Since our structuring methods allow to produce a channel waveguide in Ti:sapphire with a loss value comparable to its planar-waveguide counterpart, this structure may also lend itself to channel-waveguide lasing in Ti:sapphire.

Furthermore, we have investigated $BaSO_4:Mn^{6+}$ as a novel broadband emitting material with fluorescence emission obtained in the spectral region 900-1600 nm. $BaSO_4:Mn^{6+}$ layers were grown by liquid phase epitaxy on undoped flux-grown $BaSO_4$ [9]. Optical waveguide experiments are currently in progress. This material also shows a potential as a broadly tunable laser material in this wavelength range if excited by <2 µs pulses at 532 nm [10].

[1] A.M. Kowalevicz, T. Ko, I. Hartl, J.G. Fujimoto, M. Pollnau, R.P. Salathé, Opt. Express **10**, 349 (2002).
[2] M. Pollnau, R.P. Salathé, T. Bhutta, D.P. Shepherd, R.W. Eason, Opt. Lett. **26**, 283 (2001).
[3] A. A. Anderson, R. W. Eason, M. Jelinek, C. Grivas, D. Lane, K. Rogers, L. M. B. Hickey, C. Fotakis, Thin Solid Films **300**, 68 (1997).
[4] A. Crunteanu, G. Jänchen, P. Hoffmann, M. Pollnau, Ch. Buchal, A. Petraru, R.W. Eason, D.P. Shepherd, "Three-dimensional structuring of sapphire by sequential He^+ ion-beam implantation and wet chemical etching", Appl. Phys. A, accepted.
[5] A. Crunteanu, M. Pollnau, G. Jänchen, C. Hibert, P. Hoffmann, R.P. Salathé, R.W. Eason, C. Grivas, D.P. Shepherd, Appl. Phys. B **75**, 15 (2002).
[6] C. Grivas, D.P. Shepherd, T.C. May-Smith, R.W. Eason, M. Pollnau, A. Crunteanu, M. Jelinek, "Three-dimensional structuring of sapphire by sequential He^+ ion-beam implantation and wet chemical etching", IEEE J. Quantum Electron., accepted.
[7] L. Laversenne, A. Crunteanu, P. Hoffmann, M. Pollnau, P. Moretti, J. Mugnier, "Proton implanted sapphire planar and channel waveguides", Conference on Lasers and Electro-Optics Europe, Munich, Germany, 2003, accepted.
[8] L. Laversenne, S. Rivier, A. Crunteanu, M. Pollnau, C. Grivas, D.P. Shepherd, R.W. Eason, to be published.
[9] D. Ehrentraut, M. Pollnau, S. Kück, Appl. Phys. B **75**, 59 (2002).
[10] D. Ehrentraut M. Pollnau, "On the potential of $BaSO_4:Mn^{6+}$ for broadly tunable laser emission in the near infrared spectral region", Conference on Lasers and Electro-Optics Europe, Munich, Germany, 2003, accepted.