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Orientation-patterned gallium arsenide: engineered materials for infrared sources

David Faye, Arnaud Grisard, Eric Lallier, Bruno Gérard, Christelle Kieleck, and Antoine Hirth

Recent progress in processing low-loss quasi-phase-matched gallium arsenide crystals allows their excellent nonlinear optical properties to be employed in practical devices.

Nonlinear optical materials play a key role in the development of coherent sources of radiation, as they allow solid-state lasers to extend their emissions into new spectral ranges. This is particularly true for the 3–12μm region of the infrared spectra, which is utilized in infrared countermeasure (IRCM) devices and spectroscopic analysis, including gas sensing.

For many years, Thales Research & Technology (TRT) has been instrumental in developing nonlinear frequency conversion devices for IRCM. From devices in the late 1980s that employed phase-matched crystals to those emerging during the 1990s, which were based on quasi-phase-matched periodically-poled lithium niobate (PPLN).

While such materials have helped to advance the state of the art, they all possess inherent limitations in terms of thermal conductivity and their nonlinear coefficients, which determine the strength of nonlinear mixing. To reap the benefits of quasi-phase-matching across the 2–5μm and 8–12μm wavelength regions, TRT is therefore developing the next generation of nonlinear optical devices.

These new devices employ gallium arsenide (GaAs), which possesses several properties particularly suited to IRCM and spectroscopic applications. GaAs is transparent across the 2–12μm range and has a high nonlinear coefficient for efficient frequency conversion. Furthermore, GaAs—like all quasi-phase-matched materials—has the capacity to be engineered within broad limits to obtain a desired output wavelength from an available laser source. A comparison of the typical tuning curves obtained in the mid-infrared region with PPLN and orientation-patterned GaAs is shown in Figure 1.

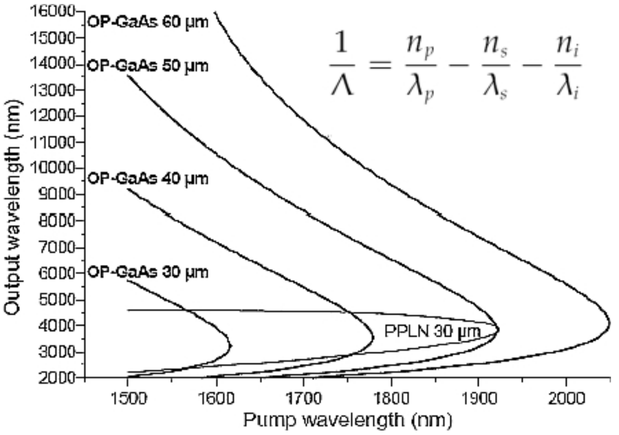

Figure 1. *Comparison of typical tuning curves obtained in the mid-infrared region with periodically-poled lithium niobate (PPLN) and orientation-patterned GaAs. Equation links pump, signal, and idler wavelengths ($\lambda_p, \lambda_s, \lambda_i$), indices ($n_p, n_s, n_i$), and grating periods Λ.*

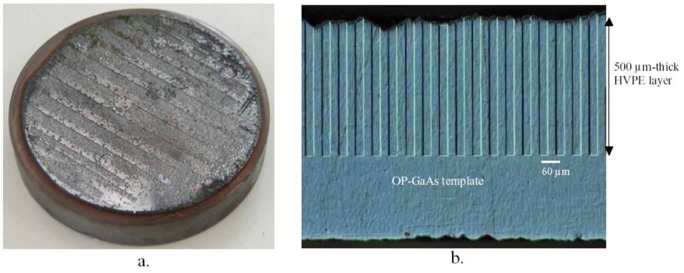

Figure 2. *(a) Top view of 2in. of OP-GaAs substrate after 30h of HVPE growth. (b) OP-GaAs cross-section of 500μm-thick GaAs HVPE film grown on 60μm-period OP-GaAs template.*

Since the refractive index of GaAs is isotropic, quasi-phase-matching is the only way to exploit its nonlinear potential. The main obstacle to developing GaAs for nonlinear devices has

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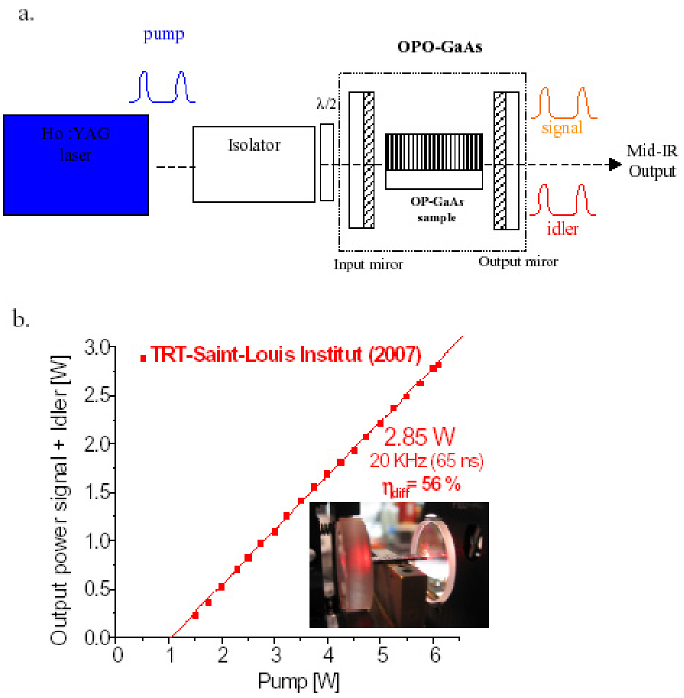

***Figure 3.** (a) Experimental setup for the OP-GaAs optical parametric oscillator (OPO). (b) OP-GaAs OPO output power versus laser pump power for a 20kHz repetition rate.*

been finding a practical method for patterning the material to produce orientation-patterned GaAs (OP-GaAs).

Based on our background in wafer bonding, we have now developed an OP-GaAs fabrication process that utilizes a dedicated pressure oven adapted to accept 2in. wafers. Standard photolithography and subsequent dry etching is then used to fabricate gratings in the wafers.

In order to produce wafers with a thicknesses in the hundreds of microns range, which are needed for device demonstration, additional material must be deposited onto these pre-orientated substrates. TRT accomplishes this with atmospheric-pressure hydride vapor-phase epitaxy (HVPE).[1] This near-equilibrium technique allows the perfect conservation of initial template crystallographic inversion, with growth rates up to 30μm/h. An example of a cross-section of a 500μm-thick OP-GaAs sample produced by the HVPE technique is shown in Figure 2. Our laboratory remains the only European facility able to provide this technology, although two research groups in the US are pursuing similar research.[2]

In initial tests, the efficiency of an OP-GaAs-based optical parametric oscillator (OPO) was limited by losses. Thanks to improvements made to our fabrications process and the subsequent reduction in these losses (around 0.02cm^{-1} at 2.09μm), we report what is, to our knowledge, the highest efficiency (56%) and average power (2.85W) achieved with a GaAs OPO in the mid-infrared region (3–5μm) pumped by a 2.09μm Ho:YAG (holmium-doped yttrium aluminum garnet) laser.[3]

In the future, we plan to increase the average power of our mid-infrared OPO, probably by increasing the thickness of the OP-GaAs sample (to more than 1mm rather than 500μm). We also plan to reduce the optical losses of the samples reaching the continuous-wave OPO regime.

Author Information

David Faye, Arnaud Grisard, and Eric Lallier
Laser and Nonlinear Optics Group
Thales Research & Technology Fr
Palaiseau, France

Bruno Gérard
Alcatel-Thales III–V lab
Palaiseau, France

Christelle Kieleck
Division OPL
Institut Franco-Allemand de Recherches de Saint Louis
Saint-Louis, France

Antoine Hirth
Institut Franco-Allemand de Recherches de Saint Louis
Saint-Louis, France

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