Proposal of a new Approach to the Electrooptical Gyroscope: the GaAlAs Integrated Ring Laser

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We propose a new approach for the miniaturization of electrooptic gyroscopes aimed to attitude control applications. The active sensing region is a semiconductor ring cavity in GaAlAs and the working principle is the same as for the well-known RLG made by He-Ne laser, but takes full advantage of the solid-state integrated technology to shrink the overall sensor size to 1 cm or less. From the calculations, we show that performance requirements demanded by robotics as well as by automotive and space actuators applications can be met with the standard available technology of GaAs diode lasers.

1. Introduction

THE ELECTROOPTICAL GYROSCOPE is a well-known and well-engineered attitude sensor for the measurement of the inertial rotation by means of the Sagnac effect in a closed optical path. The state-of-the-art technology to build a gyroscope, either RLG (ring laser gyro) or FOG (fiber optical gyro) has been presented in a number of reviews [1,2], and many are the reported segments of application [1-6].

Briefly, the RLG is built around a square or triangle cavity He-Ne laser, which sustains two counterpropagating oscillating modes. The modes exhibit a slight frequency difference $\Delta\nu = (p/\pi\lambda)\Omega$ [1] because of the Sagnac effect in the path perimeter p of the cavity when subjected to the inertial rotation rate Ω; a recombining prism allows beating of the modes on a photodiode, so as to recover $\Delta\nu$. By counting the periods of $\Delta\nu$, one has the inertial rotation angle $\Phi = \int\Omega dt$ in units of $\pi\lambda/p$ per count (as small as 2 arcsecond for p = 20 cm at λ = 0.633 µm)with typical noise of 0.001°/√h. The RLG flies in the INU (inertial navigation unit) aboard any new airliner since ten years, and is a very mature and reliable sensor albeit difficult to miniaturize [3] to, say, less than 12 cm by perimeter.

On the other hand, the FOG takes advantage of the optical fiber technology. It uses a 100-300m long mono-mode fiber coil, approx. 5-8 cm in diameter, a beamsplitter coupler to enter the coil from both ends, and reads the Sagnac optical phaseshift φ_s after propagation in the coil and recombination on a photodiode [1]. The signal is $\varphi_s = (8\pi A/\lambda c)\Omega$ and the typical sensitivity performance is Ω_n = 0.1-1°/h as limited by residual non-reciprocities of the fiber and optical components. A minimum realistic FOG size is not less than 20-30mm in diameter [4], what brings some automotive [5] and bioengineering [6] segments into the reach of the FOG, yet excluding the robotic and space ones. In fact, for these applications, all the parts (sensor and conditioning electronics) should fit into 1 cm^3 and possibly even less, while the sensitivity is relaxed to, say, Ω_n = 0.01-0.1°/s [1,4,5].

In this letter we propose an integrated-RLG approach matching this requirements.

2. The integrated RLG

The basic proposed configuration is shown in figure 1. On a GaAs substrate, a ring active waveguide in GaAlAs is grown with standard technologies. When pumped above the threshold current, the waveguide will sustain two counterpropagating laser modes, which can be made single transversal by properly designing the guide width and index difference, and single longitudinal by not exceeding a certain value of the perimeter. A straight waveguide (also pumped at transparency) will couple some power out of the ring for modes recombination (considered later).

With a responsivity $R = \Delta\nu/\Omega = 2R/\lambda$ [typ. R = 7 kHz/(r/s - radians per second) for a 3-mm radius R at λ = 850 nm] the gyro yields the following frequency difference $\Delta\nu$ for some selected applications: $\Delta\nu$ = 60Hz for robotics (Ω = 0.5°/s), 5 Hz for the automotive (0.04°/s), 0.5 Hz for the earth rotation (15°/h).

These figures are to be compared with the intrinsic frequency noise associated with $\Delta\nu$ and due to amplified spontaneous emission $n_{sp}h\nu G^2F$, where F is the noise figure of the loop-gain G and n_{sp} the inversion factor. Using the basic relation $\Delta\varphi = E_{sp}/E_0$ for the instantaneous

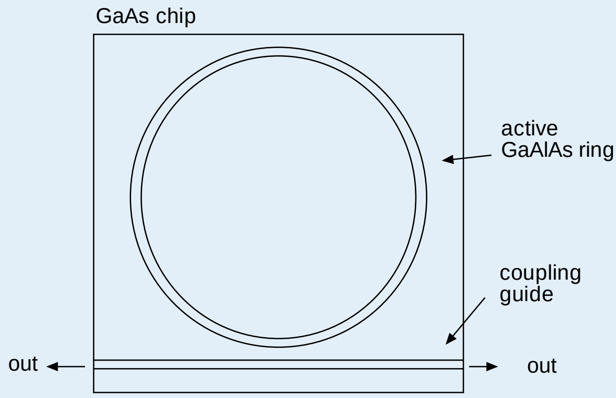

Figure 1 **Ring laser schematics.**

(random) phase fluctuation and calculating the associated frequency deviation $\Delta\nu = (1/2\pi)d\Delta\varphi/dt$, the well known expression [1] for the error in frequency difference of two identical modes on a bandwidth B is:

$$\sigma^2_f = \Delta\nu_c^2\, h\nu\, G^2\, F\, B\, /P_0 \quad (1)$$

where $\Delta\nu_c$ is the cavity linewidth and P_0 is the (internal) laser power in the ring. Evaluation of (1) gives as a quantum limit σ_f =1 Hz for $\Delta\nu_c$ = 200 MHz, a value that requires stringent low losses per unit length in the ring, i.e. α_{tot} = 0.1 cm^{-1}.
Of course, the gyro at rest would be locked with the two counterpropagating waves at the same frequency, because of residual coupling. The locking equation [1] is described by the well known Adler relation for the field phase φ:

$$d\varphi/dt = A + B \sin\varphi \quad (2)$$

where A<<B means locking ($d\varphi/dt$ = 0), A=B marginal lock-out and A>B normal oscillation regime with the desired solution $d\varphi/dt$ = A. In (2) it is $A = 2\pi\Delta\nu$ (the rotation signal) and $B = \alpha_{sc} c\omega_c/2\pi$ is the coupling rate proportional to the scattering loss α_{sc} (a fraction ≈ 0.01-0.1 of the total loss α_{tot}) and to the recapture ratio in backscattering $\omega_c/2\pi$, $\omega_c = NA^2$ being the solid angle of diffraction of the mode. With appropriate values in (2), we get A = B = 4 kr/s as the lockout value. Now, let us apply a dither [1] by letting $A= 2\pi\Delta\nu + \omega_d\Phi_d \sin \omega_d t$, where the new term is the angular velocity applied by the dither, at a frequency ω_d and with an amplitude of rotation Φ_d. We can now have de-locking if $\omega_d\Phi_d$ is larger than B, what requires e.g. ω_d = 100 kHz and Φ_d =7 mr, a set of reasonable values that can be implemented by a small piezoceramic disk driven in the shear mode of vibration.

3. Structures

The active waveguide is of a type already studied for very small ring lasers, intended for telecommunication applications [7]. The transversal section of the waveguide (shown in Figure 2) is a ridge-like guiding structure. The active layer is a double quantum well to ensure high gain per unit length and low threshold.
For the recombination, amongst the several possible alternatives the best are those which avoid spurious oscillations on the coupler waveguide end-faces. In fact, as the length of the coupler is not negligible (a few mm or more) the coupler shall be pumped too (at least at transparency). Also, the modal laser distribution should be not distorted by the coupler. Two possible configurations, which are near to be completed for fabrication, are shown in figure 3.
The first configuration ends in a 50/50% coupler on the chip edge, where the detection photodiode can be placed. The facet cleaved at an angle (tip. 7 deg) ensures a negligible reflection at the output. In the second possibility [8] the coupler is inside the ring, thus requiring a smaller radius of curvature, but the loss increase can be tolerated and room is availeble to allow for the photodiode. In both configuration, the coupling factor out of the ring is kept low (typ. a few percent) so as to avoid spurious reflections and to enhance the cavity quality factor (low $\Delta\nu_c$).

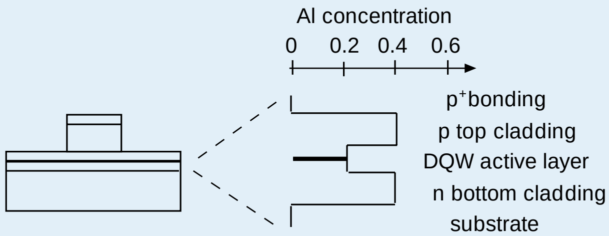

Figure 2 **Waveguide details.**

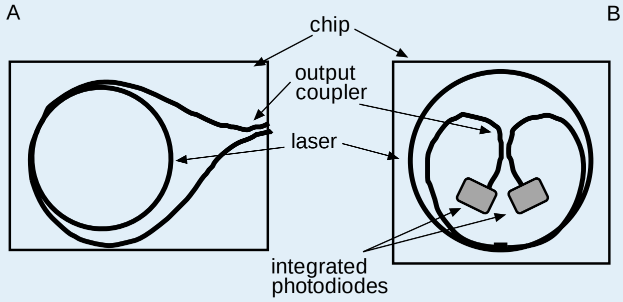

Figure 3 **Output coupler options.** A **off-chip output;** B **with integral photodiodes.**

4. Conclusions

A new integrated ring laser gyro has been proposed. System evaluations of the performances are encouraging, and the device seems attractive for application in space and robotics areas.

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