NARROW LINEWIDTH LIGHT SOURCES FOR SPACE INTERFEROMETRY

Final Report

JPL Task 974

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A. OBJECTIVES

The NASA Origins program theme emphasizes separated space interferometers, tethered interferometers using multiple satellites, and other constellations/formations as enabling technology for very large baseline interferometers in space. The necessary precise positioning of the participating spacecraft will be achieved using optical metrology. The fine-gauge metrology is based on frequency-stable narrow-linewidth light sources. This work will advance the state of the art by producing integrated optics (IO) resonators critical for the narrow linewidth operation of semiconductor and diode pumped Nd:YAG lasers. The potential applications of such components in interferometry projects are numerous.

The most significant result of this work will be enabling absolute metrology in space. The proposed resonator will be the critical component for fabricating pairs of narrow linewidth semiconductor lasers separated by 1-10 nm. One can not perform absolute distance measurement (i.e. determine distance without ambiguity) using a single wavelength -- all distances separated by a full fringe ($\lambda/2 \approx 0.65$ μm) will produce the same reading. This ambiguity could be resolved by using an additional ranging system to determine the distance coarsely, with $\leq\lambda/2$ precision. However, the existing RF and optical ranging systems have ≈1mm precision, and therefore a gap exists between the fine and the coarse measurement gauges. Bridging the gap is required to enable absolute distance measurement. To this end, a pair of narrow linewidth semiconductor lasers separated by 1-10 nm will enable measurements with an ambiguity range of several mm while still enabling submicron precision. (Pairs of Nd:YAG lasers cannot be used for this purpose as they can only be tuned by ≈0.1 nm away from the 1.319 nm line).

Enabling narrow linewidth operation of semiconductor lasers can be of further use for the interferometry projects. While the current light source of choice, Nd:YAG laser, operates at 1.319 μm, the communication industry concentrates its efforts at the 1.55 μm range. Therefore the IO components necessary to build the complete metrology system (e.g. switches, couplers, optical amplifiers and frequency shifters and modulators) operating at 1.3 μm are either non-existent or hard to find. Thus building narrow linewidth semiconductor lasers in the 1.55 μm range will solve difficult systems problems.

Furthermore, metrology systems currently use frequency-stabilized Nd:YAG lasers as light sources for fine-gauge metrology. The lasing frequency is stabilized by closing a frequency control loop using a high quality factor (Q) resonator as a frequency discriminator. The advantage of the proposed IO resonator over Fabri-Perot etalons currently in use will be the

increased flight worthiness and ease in system integration, as well as considerable space and weight savings.

B. PROGRESS AND RESULTS

1. Science Data

We have built two types of ring resonators. The first type (type 1) is built with waveguides that have large modes suitable for the direct fiber coupling. These resonators will replace the bulk Fabry-Perot etalons used in the metrology systems. The type 2 resonators are based on waveguides with oblong modes that fit the semiconductor laser modes. These resonators will be useful in linewidth narrowing of semiconductor lasers. The waveguide cross sections are depicted in Figure 1.

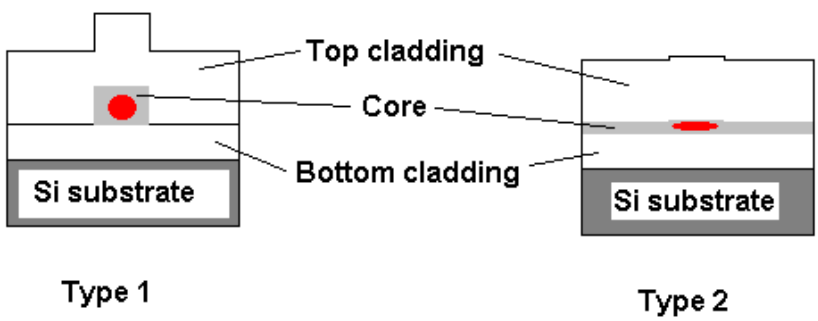


Figure 1. Waveguide layout.

We have calibrated PECVD growth process for a number of materials with different refractive indexes. Table 1 shows the materials with the correspondent stresses and refractive indexes.

Table 1. PECVD material growth calibration

Recipe name	Material	Refractive index at 1.55 μm	Stress dyn/cm^2	Growth rate A/sec.
LORTOX	SiO_2	1.452	-3.2×10^9	382
SION3	SiO_xN_y	1.501	1.5×10^9	275
SIN1-1	Si_xN_y	1.851	1.2×10^{10}	86

Resonators with large waveguides (type 1) have been built. The LORTOX recipe was used for the cladding material while the SION2 recipe was used for the core. The waveguides were defined by contact photolithography. The reactive ion etching was then used to transfer the pattern onto the core layer.

We have tested both the direct masking by photoresist and a more involved process with an intermediate step creating a Cr masking layer to define the waveguides. Both processes worked well. The RIE etching with CHF_3 of the Cr masked wafer resulted in a vertical wall profile as is shown in Figure 2.

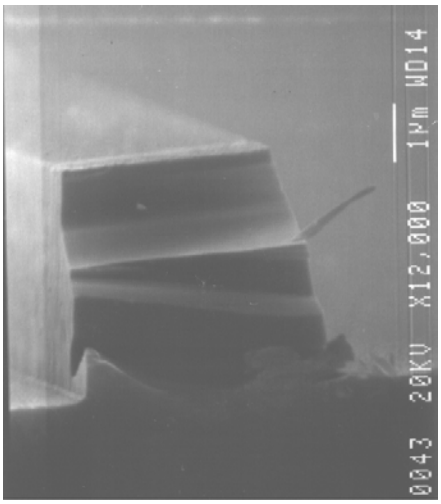


Figure 2. Waveguide etched using Cr mask.

The same etching recipe used on the wafer masked with the photoresist produced slightly slanted walls Both wall profiles are satisfactory.

However, we experience difficulty with the regions where waveguides are running close together, i.e. the ring to straight section coupling regions. As shown in Figure 3, the growth of the cladding material is non-conformal and causes air pockets between the waveguides.

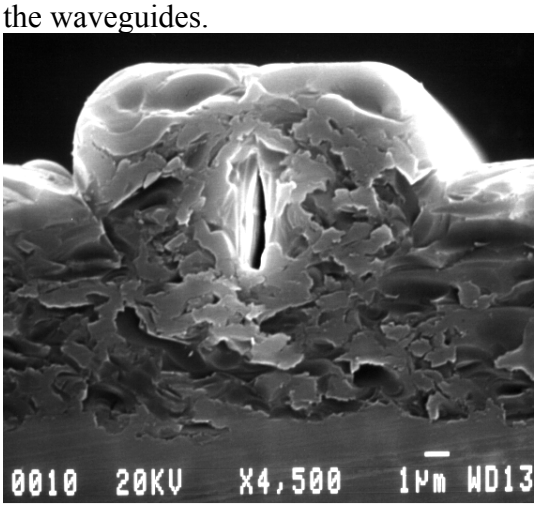
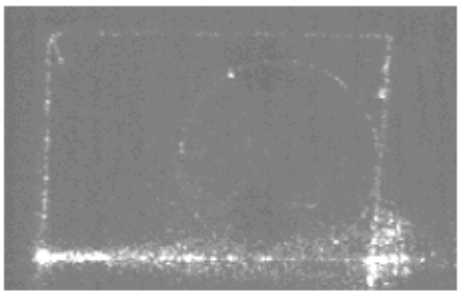


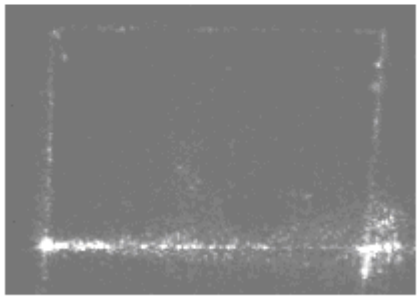
Figure 3. Notice the void in the center between the waveguides due to non-conformal growth.

Our calculations show that these air pockets reduce the coupling to unacceptably low levels. Methods for eliminating these pockets are well known. The preferred technique is to use boron-doped glass as the top cladding. This material can be reflown after deposition for conformal coating without voids.

We have also made a series of ring resonators with oblong modes that fit the mode of a semiconductor laser. These resonators will be useful in linewidth narrowing of semiconductor lasers. The LORTOX material core and SIN1-1 cladding materials were grown by PECVD; the processing sequence was similar to the one described above. The waveguide design has a shallow rib and therefore the overgrowth with the top cladding does not present difficulties encountered in the large waveguide case. These ring resonators are currently being tested at 1.55 μm. We have obtained pictures with an infrared camera of a ring resonator at resonance and off resonance (see fig. 4).



At resonance



Off resonance

Figure 4. Infrared camera pictures of the ring resonator at resonance and off resonance.

The losses in these waveguides were measured using transmittance characteristics of the rings. As shown in Figure 6, the transmittance spectrum of a ring resonator exhibits periodic notch-like structures. Using the finesse (the ratio of the notch width to the periodicity) and the depth of notches, one can compute the loss in the ring. The spectrum in Figure 5 corresponds to a loss of 1.4 dB per turn or 1.5 dB/cm.

We have computed the possible laser linewidth narrowing, using such rings along the lines suggested in the original proposal. Chirp reduction factors of more than 40 are achievable (linewidth narrowing by more than a factor of 1600 is possible). This result is very encouraging, and we will pursue this technique for the semiconductor linewidth narrowing using other funds.

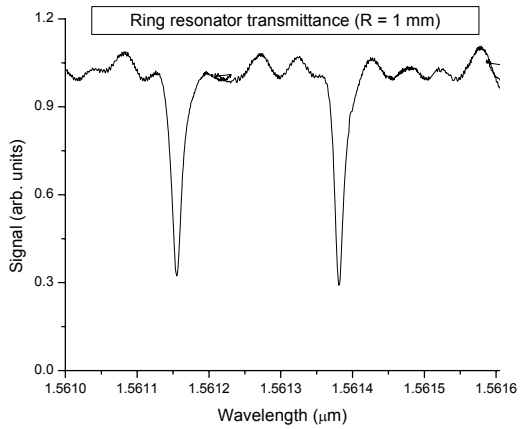


Figure 5. Transmittance spectrum of a ring resonator.

C. SIGNIFICANCE OF RESULTS

We developed ring resonators for space applications. In particular, the ring resonators for the semiconductor linewidth narrowing has been successfully produced.

D. FINANCIAL STATUS

The total funding for this task was $100,000, all of which has been expended.

E. PERSONNEL

No other personnel were involved.

F. PUBLICATIONS

None.