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Monolithically integrated optical displacement sensor in GaAs/AlGaAs

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A monolithically integrated displacement sensor has been fabricated in the GaAs/AlGaAs material system. The device is configured as a Michelson interferometer and consists of a DBR laser, a directional coupler, transparent waveguides and a photodetector. Interference fringes could be seen at a measurement distance of up to 45cm, requiring only the alignment of an external GRIN lens for beam collimation.

Introduction: The monolithic integration of lasers and interferometers is one of the most important steps towards the realisation of photonic integrated circuits for sensing applications. For displacement measurement using an integrated optical approach, Michelson interferometers based on glass, $LiNbO_3$ or silicon have been presented [1 – 4]; all of these technologies, however, require external mounting and alignment of a light source, since monolithic integration of a laser is not yet possible in these materials.

We present here the first demonstration, to our knowledge, of a GaAs-based monolithically integrated displacement sensor. The device is configured as a Michelson interferometer and consists of a DBR laser, a photodetector and transparent waveguides, all monolithically integrated on a single piece of GaAs. The fabrication of such monolithically integrated sensors requires a simple laser fabrication technology, compatible with the interferometer fabrication process, and a postgrowth bandgap engineering process to define transparent areas for the Bragg reflector and the waveguides and absorbing sections for the laser and the photodetector. Furthermore, the measurement of small optical signals needs good electrical isolation between laser and photodetector. The first of these three requirements was fulfilled by the use of a so-called grating recess, allowing the fabrication of the DBR laser without regrowth [5]. The second was accomplished by vacancy-enhanced quantum well disordering (VED) [6], while the third could be achieved with a proton implantation step.

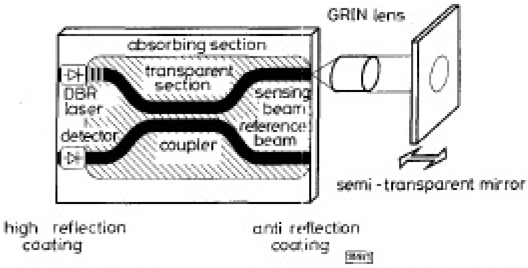

Fig. 1 *Schematic diagram of monolithically integrated Michelson interferometer with characterisation setup*

Fabrication process: The displacement sensor is shown schematically in Fig. 1. The light generated by the DBR laser is divided into a reference and a measurement beam by the directional coupler. After reflection at the cleaved facet and from the external object mirror, the two beams interfere and are detected in the photodetector. The ridge waveguides were 3mm wide and had curve radii of 500µm, therefore requiring strong index-guiding achieved by etching through the waveguide core. Three different coupler lengths (100/275/450µm) and two Bragg reflector lengths (150/200µm) were employed. The pumped laser sections and the photodetectors were both 500µm long.

The fabrication technology of this device was similar to that published previously [7]. The layer structure was a MOVPE-grown single-quantum-well double-heterostructure with a 160nm core and two 1µm cladding layers. For the VED process, 200nm of SiO_2 were evaporated on the transparent sections (Bragg reflector, waveguides, coupler), while a 250nm thick SrF_2 layer was used on top of the absorbing sections (laser, photodetector) to prevent intermixing. VED was accomplished by a rapid thermal anneal at 960°C for 30s, followed by the complete removal of the dielectric layers from the wafer surface. A photoluminescence shift difference of 20nm was seen after this annealing step.

Proton implantation for electrical device isolation (a dose of 4×10^{15}cm^{-2} at three different energies, 40/70/100keV) was done everywhere outside the waveguiding areas; in addition, 2µm wide stripes were implanted across the waveguides between active devices to electrically isolate the components without markedly increasing the waveguide losses. The processing was then completed using standard waveguide etch and metallisation techniques.

On the cleaved facet of the DBR laser (left side of Fig. 1), a high reflectance Al-mirror was evaporated to improve laser threshold (60nm SiO_2 for isolation, 120nm Al as mirror), while on the measurement side of the interferometer (right side of Fig. 1), an antireflection coating (Balzers PASO III) was used to reduce coupling losses of the measurement beam and to attenuate the reflected reference beam. The remaining reflectance of 2% was still sufficient for the reference beam to produce a distinct interference signal.

Characterisation and measurement results: For performing a displacement measurement, the DBR laser was driven CW at room temperature with an injection current of 50mA. Its threshold current of ~35mA resulted in a threshold current density of 2.2kA/cm^2; emission wavelength was 820nm.

The photodetector was reverse biased at –5V and had a leakage dark current of 500pA; responsivity of such detectors is typically 0.5A/W. The electrical resistance between the laser diode and the adjacent photodiode was measured to be in the order of 10GΩ. Since the absorption edge was blue-shifted by only 20nm, the waveguide losses were relatively high (40dB/cm) owing to band-edge absorption.

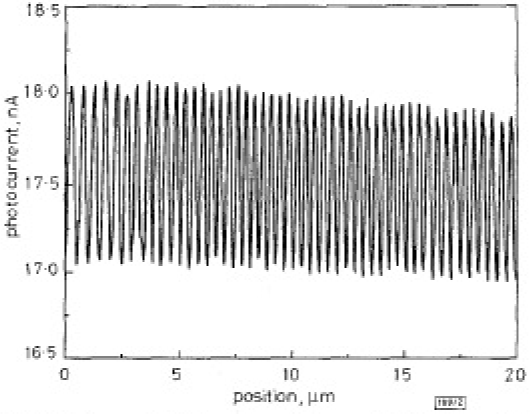

Fig. 2 *Interferogram for 13cm mirror distance and 95% mirror reflectance as measured by integrated photodetector*

The interferometer chips were tested in bar form and were Peltier temperature-stabilised to better than 0.1K. The measurement beam, collimated by an external GRIN lens, was directed onto a semitransparent mirror through which the reflected beam position could be observed by a CCD camera. Observation was necessary to adjust the beam properly into autocollimation. The semitransparent mirror was fixed to a piezo-driven, gimbal-mounted holder with which the measurement distance could be varied between 3 and 45cm. With this arrangement, we were able to measure a 20μm movement (limited by the travel of the piezo-actuator) which led to 49 interference fringes, each of them corresponding to a mirror movement of 410nm (see Fig. 2). Displacements of a quarter of a fringe, or approximately 100nm, were resolvable. The measured interference signal showed a good temporal stability but was very sensitive to vibration of the external components.

A large constant offset in the photodiode current, dominated by optical crosstalk between laser and photodiode, was seen. To evaluate this current, we removed the external optics and measured the signal magnitude. Since we know the approximate reflectivity of the AR-coated facet (2%), we were able to estimate the crosstalk current from this measurement, leading to a value of 16.7nA. This value agreed well with a more comprehensive measurement involving the use of five different external mirrors with differing reflectivities. Subtracting the crosstalk current from the signal values shown in Fig. 2 results in a considerably improved contrast.

The crosstalk current can be reduced by an isolation trench between laser and photodiode. For practical use, the functionality of the interferometer must be enhanced by the inclusion of a phase shifting element as part of a double-arm interferometer allowing quadrature detection for determination of displacement direction as well as magnitude.

Conclusion: A single monolithically integrated Michelson interferometer chip used as an optical displacement sensor was designed, fabricated and tested. Interference fringes were seen at a distance of up to 45cm. The only element requiring alignment was the external GRIN lens for the collimation of the measurement beam.

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