Polarisation stabilisation of telecom lasers by minimally-invasive direct-write focused electron beam induced deposition

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ABSTRACT

Gas assisted focused electron beam induced deposition was used as a maskless, dry, and minimally invasive nanofabrication concept to stabilize the polarisation of individual vertical cavity surface emitting lasers (VCSELs) on a wafer in a single post-processing step [1]. Using a 30 keV focused electron beam of a scanning electron microscope and injecting volatile dimethyl-gold-trifluoroacetylacetonate molecules, polarization grids were directly written on VCSELs by dissociating the surface adsorbed molecules. The electron triggered adsorbate dissociation resulted in electrically conductive Au-C nanocomposite material with gold nanocrystals embedded in a carbonaceous matrix. This material proved successful in suppressing polarization switching when deposited as line grids with a width of 200 nm, a thickness of 50 nm, and a pitch of 500 nm and 1µm.

Keywords: laser, polarization, focused electron beam induced deposition (FEBID)

1 INTRODUCTION

The possibility to deposit or remove very small amounts of material for tuning purposes on a fully processed micro/nanodevice at the right place at will without damage to surrounding sensitive areas can be very cost effective even if the speed of deposition (or etching) is very low compared to standard photolithography. Here, we describe an emerging direct-write nanoscale patterning concept, based on gas-assisted focused electron beam induced deposition (FEBID) [2,3], which enables local deposition of conductive material for refining the performance of a vertical-cavity surface-emitting laser (VCSEL), see fig. 1. Long-wavelength emitting VCSELs in the 1310 nm range offer numerous advantages for applications in local and access networks and optical spectroscopy thanks to their low power consumption, high speed modulation, and ease of coupling to optical fibers [4]. However, due to the cylindrical symmetry of these devices typically made on standard (100) GaAs or InP substrates, they suffer from the lack of a stable polarization state and hence the polarization can flip along orthogonal <100> directions during operation, i.e. during current injection.

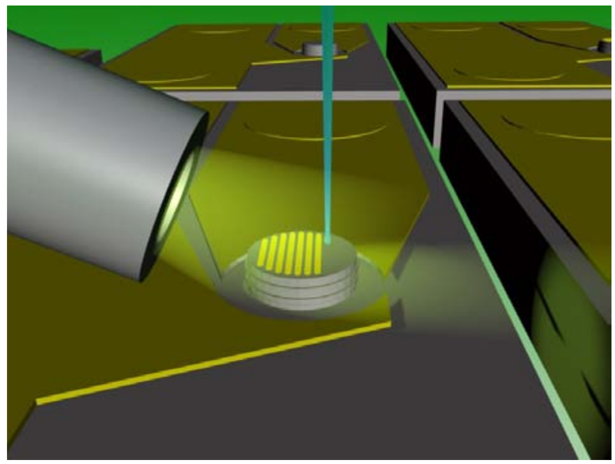

Figure 1: Scheme of gas-assisted focused electron beam induced deposition (FEBID) for laser tuning. By scanning the focused electron beam, polarization gratings can be locally deposited on top of individual VCSELs without the need for masks, lithography resist removal, or wet chemistry steps.

2 RESULTS

2.1 Gas assisted focused electron beam induced deposition

Figures 2 and 3 show scanning electron microscope photographs of the gratings deposited on the VCSELs. Dimethyl-Gold-trifluoracetylacetonate was used for the local dissociation by a focused electron beam. The deposit was a gold-carbon nanocomposite with 30 at.% Au embedded as nanocrystals in a carbon matrix.

The volatile dissociation reaction products desorb into the vacuum chamber of the scanning electron microscope (SEM) and are removed by the vacuum system, while the non-volatile dissociation products form the deposit. Since the molecules are continuously supplied to the substrate surface via a gas injection system, the deposition can be continued to produce to (almost) any desired three-dimensional deposit shape by moving the focused electron beam or keeping it stationary. Once the desired structure is written, the gas injection system is closed and the non-dissociated molecules desorb, leaving the desired lithographic deposit pattern on the surface.

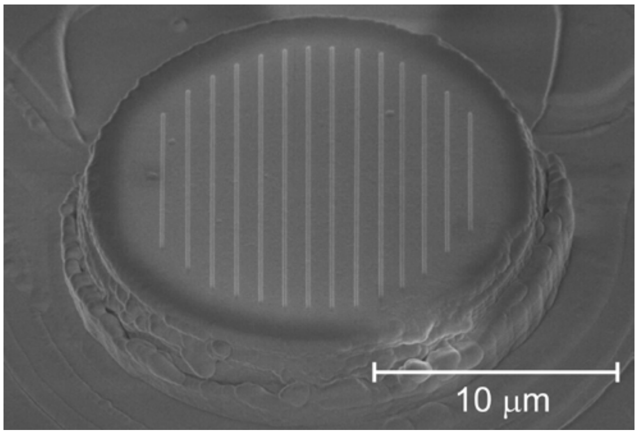

Figure 2: Vertical cavity surface emitting laser (VCSEL) with polarization grating directly written by gas assisted focused electron beam induced deposition (FEBID). Gold containing gratings of 1 µm distance were locally written using a Me2-Au(tfa) (CAS 63470-53-1) precursor.

This nanolithography concept is, by its nature, maskless and single-step in contrast to standard resist based lithography and lift-off procedures. It does not require any wet chemical step, does not implant any material (which is the case when using focused Ga-ion beams) and thus is minimally invasive to sensitive underlying and surrounding structures and devices.

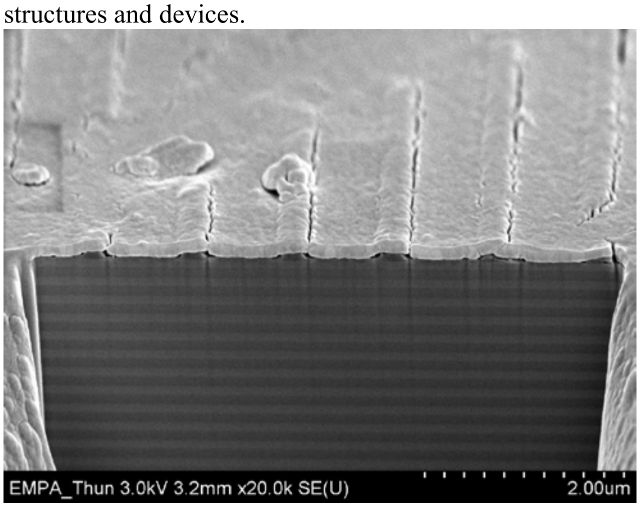

Figure 3: FIB cross section of the polarization grating deposited via FEBID on the surface of the (Al,Ga)As multilayers constituting the top distributed Bragg reflectors of the VCSEL. The grating thickness was 76.5 nm, the FWHM size was 196 nm, and the grating pitch 1 µm. A platinum film (light contrast) was evaporated on the surface prior to FIB milling for protection.

2.2 VCSEL Polarization

Figure 4 shows the successful stabilization of the initial P0° polarization of a VCSEL by depositing a grating on its top surface.

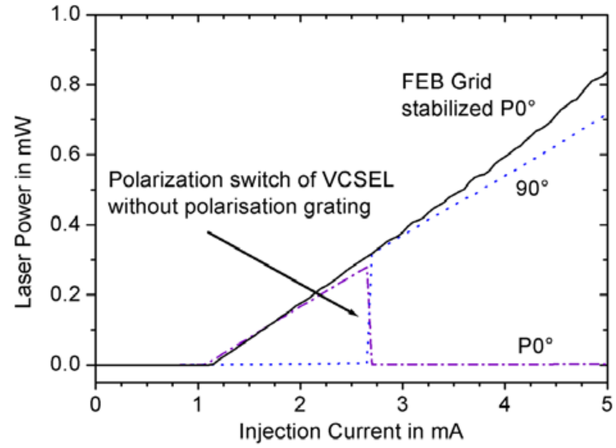

Figure 4: Suppression of polarization switching by direct-written polarization grating via gas assisted FEBID. Without grating, the VCSEL showed a 0° to 90° polarization switch at around 2.7 mA injection current (dashed lines). The grating stabilized the 0°-polarization (full line) while suppressing the 90°-polarization.

Microellipsometric measurements performed with an spectroscopic imaging ellipsometer (nanofil_ep3se, Accurion GmbH, Göttingen) on the nanocomposite gold-carbon deposit gave a complex refractive index n = 2.2+0.8i at 1000 nm wavelength.

ACKNOWLEDGEMENTS

We would like to acknowledge financial support from European Commission in the 7th Framework Programme (Grant Agreement n°260079).

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