ESRF	**Experiment title:** Mapping of shear strain in suspended GeSn micro-disks for light emission	**Experiment number**: MA-4937
Beamline: ID01	**Date of experiment**: from: 10.09.2021 to: 14.09.2021	**Date of report**:
Shifts: 12	**Local contact(s)**: Edoardo Zatterin	*Received at ESRF:*

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Report:

The aim of the proposal was to characterize the lattice strain ε, lattice rotation w and alloy composition x in suspended Ge$_{1-x}$Sn$_x$ micro-disks, such as shown in the SEM image in Fig.1a. Such disks find application as fully CMOS-compatible group IV diode and lasers for the infra-red (IR) regime. The suspended disks are fabricated by chemical underetching from epitaxially grown Ge$_{1-x}$Sn$_x$ /Ge heterostructures. [1] The free-standing parts are not in contact to the Ge-substrate anymore and are thus strain-relaxed, which allows to shift the band structure of the Ge$_{1-x}$Sn$_x$ alloy towards a direct bandgap. Thus, IR lasing can be achieved and the lasing temperature can nowadays reach up to room temperature. The under-etching is also expected to remove the misfit dislocations that are introduced in the process of partial plastic relaxation during growth of the Ge$_{1-x}$Sn$_x$ film. [2]

The removal of geometrical constraints during under-etching allows elastic relaxation of the rim of the discs, which also results in a certain warpage. The strain relaxation in this micro-structure is therefore a rather complex 3D problem, the knowledge of which is critical for understanding the optical properties of the device. In particular, shear strain had been discussed to be detrimental to devie performance. However, a non-invasive measurement of the different components of strain with high resolution is not routinely available. Scanning X-ray diffraction microscopy (SXDM) has been demonstrated to be one (if not the only) non-destructive experimental techniques sensitive to shear strain on a submicron spatial scale.[3]

We used SXDM to non-destructively study the strain distribution in a set of three microdisks differing in layer thickness and alloy content. We used the recently established technique[4] of recorded SXDM datasets for three different, symmetry-equivalent Bragg reflections of the {335} family from the Ge$_{1-x}$Sn$_x$ layer, in order to maximize the lateral strain sensitivity of the measurement and to maintain an equally small the probing volume for all datasets. In particular, this choice of reflections at the used energy of 9.5 keV led to near-normal incidence and grazing exit of the X-rays, leading to the best spacial resolution and a high inclination angle of the diffracting lattice planes.

The Sn *L* X-ray emission was picked up in parallel using an energy-dispersive X-ray detector, which is an orientation-independent signal and, hence, allowed us to track the sample drift with changing incidence angle. This was crucial, since we observed a strong curvature of the sample which leads to a strong apparent spatial movement of sample regions that fulfil the Bragg condition (as seen in Fig. 1b), with changing angle. This curvature also forced us to cover a wider angular range in the SXDM measurement as usual.This was achieved by by moving the detector close to the sample as well as by scanning a large range of incidence angles (6 deg). However, in some datasets and for some strongly tilted regions of the sample, the diffraction signal still left the angular range covered by the measurement.

The analysis of the SXDM data for this proposal is completed and the lattice strain and alloy composition were calculated following previously published procedures,[3-5] In the map of a symmetric strain component ε_{zz} (panel c) the elastic relaxation of the rim of the disk is observed, while the shear strain (panel d) shows a quadrupole-like pattern around the circumference of the supporting Ge pillar. The alloy composition (panel e) shows fluctuations resulting from strain variations that build up during epitaxial growth due to an inset of plastic relaxation by a misfit dislocations network (along <110> directions) when the critical thickness. These effects are investigated and discussed in an upcoming publication together with Finite Element Method (FEM) simulations and complementary experimental techniques.

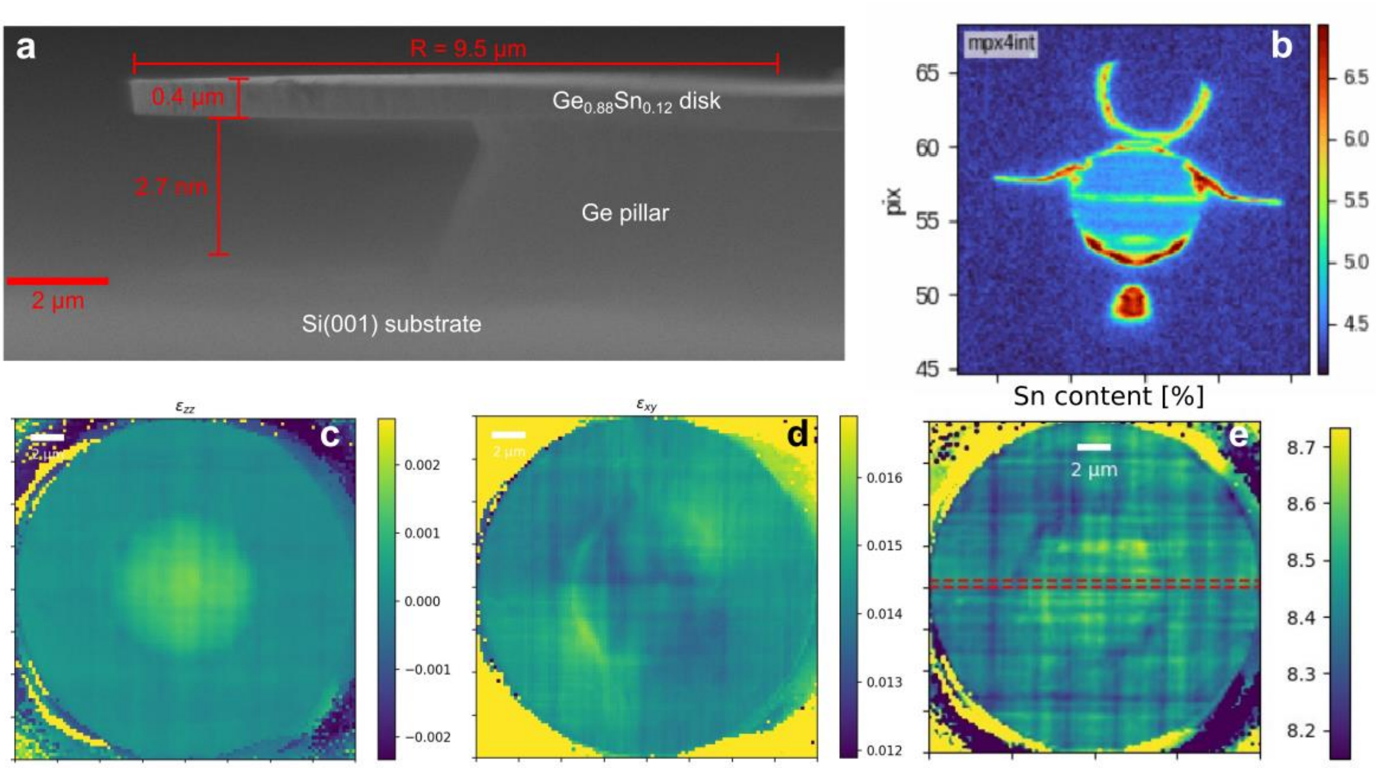

Fig. 1: (a) SEM image of the suspended $Ge_{0.88}Sn_{0.12}$ micro-disk, (b) spatial map of the X-ray intensity from the 335 Bragg reflection for a fixed rocking angle, showing the strong bending and deformation of a disk, (c) map of the out-of plane symmetric strain ε_{zz}, (d) map of the in-plane shear strain ε_{xy}, (e) map of the Sn content x, calculated assuming no surface normal stress

Since the layers studied in this experiment were quite thick (> 200 nm), compared to those we successfully investigated by SXDM before, [4, 5] the intensity of the diffraction intensity was not a limiting factor for acquisition speed. Instead, the limiting factore has been the frame rate of the *Maxipix* detector. To achieve a faster data acquisition, we attempted to utilize the *Eiger* detector at ID01, since it provdes much higher framerates than the *Maxipix* detector. However, even after 1 shift of debugging, the software interface to the *Eiger* detectore was not stable enough to perform the SXDM measurements. Therefore, we fell back to the *Maxipix* detector. Moreover, a connection problem between the beamline and the MUSST card occurred, which lead to the loss of approximately 2 shifts of beamtime, during which the problem had to be identified and fixed. Nevertheless, the experiment was largely successful and the results will be published soon.

References

[1] A. Elbaz, D. Buca, N. von den Driesch, *et al. Nat. Photonics*, **14**, 375, (2020).[2] A. Elbaz, M. El Kurdi, A. Aassime *et al. Opt. Express*, 26, 28376 (2018) [3] C. Richter, V. M. Kaganer, A. Even *et al. Phy. Rev. Appl.* 2022, 18, 6 064015 [4] C. Corley-Wiciak, C. Richter, M. H. Zoellner, *et. al. ACS Appl Mater Interfaces.* (2023) 15(2), 3119-3130 [5] C. Corley-Wiciak, M. H. Zoellner, I. Zaitsev *et. al. Phys. Rev. Applied.* (2023) 20, 024056