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Elastic Strain Engineering of Group IV Materials for Low-Threshold On-Chip Lasers

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Abstract

In this talk, we discuss our recent efforts on the development of strain-engineered group IV lasers for their use in photonic-integrated circuits.

1. Introduction

Since the invention of the first transistor over half a century ago, transistor scaling has led the semiconductor industry to blossom. Despite the improved performance of scaled transistors, however, the computational speed of integrated circuits (ICs) has now become limited by their electrical interconnects [1]. To alleviate this performance bottleneck in ICs, optical interconnects, which have already revolutionized long-haul communications, have recently gained much attention for on-chip applications [2]. Over the past decade, many of the key constituents of an on-chip optical interconnect system, such as high-performance photodetectors and modulators, have been demonstrated on a silicon-compatible platform [3]–[5]. However, an efficient light source remains particularly challenging; silicon and silicon-compatible materials such as germanium (Ge) are not readily suitable for light emission because their band gaps are indirect. It has been proposed to use tensile strain to make Ge's band gap become direct and therefore suitable for creating on-chip lasers [6]; however experimental realization has thus far been lacking.

In this talk, we will focus on developing an efficient silicon-compatible light emitter based on strained Ge technology. Starting from theoretical calculations showing how tensile strain can improve the light emission efficiency of Ge [7], we will present several approaches for enhancing light emission from highly strained Ge on a CMOS-compatible platform [8]. We will introduce a uniaxial approach that can potentially create a direct band gap Ge wire using geometrical amplification of a small pre-existing strain [9], [10]. We will also present our recent demonstration of strained Ge lasers that attains orders of magnitude lower thresholds compared to the state-of-the-art Ge lasers [11]. We will end this talk by discussing the implications of these experimental achievements and future challenges in the field of Ge-based lasers.

2. Experimental Results

Figure 1 shows the fabrication process of our strained Ge lasers and a typical scanning electron micrograph (SEM) image of the finalized structure [11]. The germanium-on-insulator (GOI) substrate for the Ge laser was made via epitaxy and wafer bonding. A bulk Ge layer is directly grown on an 8-inch silicon (Si) (100) substrate using metal-organic chemical vapor deposition (MOCVD) reactor. After removing the top 100-nm Ge layer by chemical mechanical polishing (CMP) step for a smooth surface for bonding, a 50-nm Al_2O_3 sacrificial layer is deposited on the Ge surface by atomic layer deposition (ALD). Then the Ge-on-Si wafer is directly bonded at room temperature to an 8-inch Si (100) handle wafer with a 1-μm thick thermal oxide (SiO_2) layer. After removing the carrier Si by grinding and selective chemical etching in Tetramethylammonium hydroxide (TMAH), the Ge layer is transferred to the handle wafer, which forms a GOI substrate. Then the Ge layer of the GOI is thinned down by CMP to the desired thickness of 220 nm. The laser structure was then fabricated on GOI by lithography and etching processes. The Ge nanowire laser structure is defined by the electron-beam lithography (EBL), and its pattern is transferred to the Ge layer by reactive etching (RIE) using Cl_2 gas. The sample is wet etched in 30% KOH solvent to selectively remove the sacrificial Al_2O_3 layer forming the undercut structure. The releasing process causes the strain redistribution and amplifies the tensile strain in the nanowire.

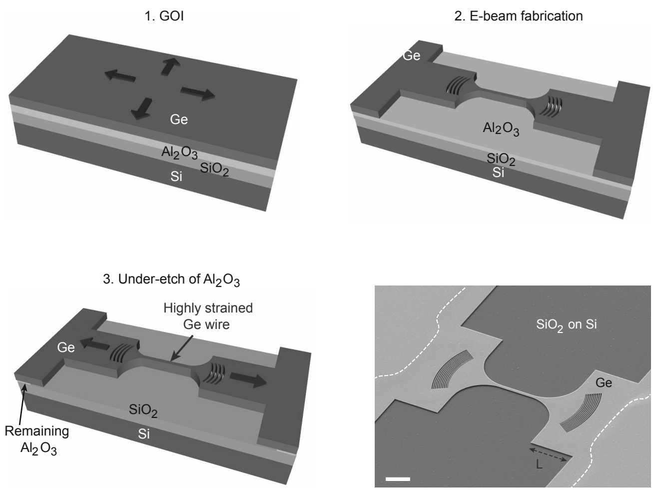

Fig. 1 Schematics of the laser structure fabrication process and an SEM image.

Figure 2 presents pump-dependent spectra (right) taken from 1.6% strained wires at 83K and integrated photoluminescence (PL) intensity as a function of pump power (left). The integrated PL output versus pump power shows a clear threshold behaviour as also shown in double-logarithmic plot (inset). The spectra at pump powers exceeding the lasing threshold (3kW/cm^2) show dominant lasing peaks near 1530nm over the spontaneous emission background.

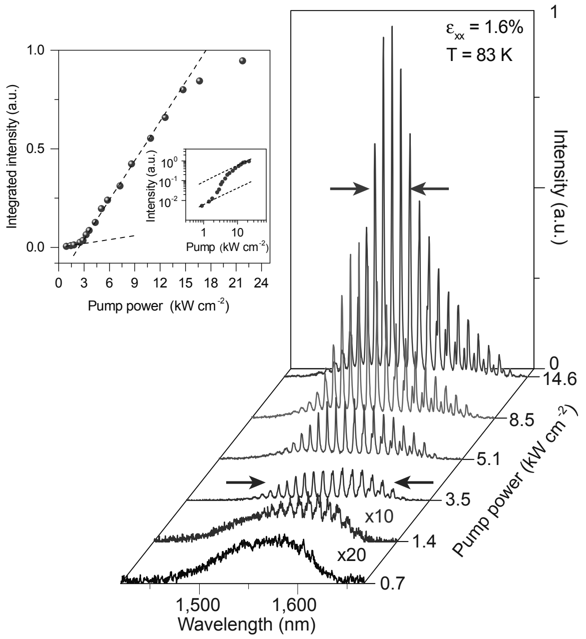

Fig. 2 Power-dependent emission spectra of a 1.6%-strained Ge nanowire (right) and integrated output intensity as a function of pump power (left).

3. Conclusions

In this talk, we review the recent development of strain-engineered group IV materials for on-chip laser applications.

Acknowledgements

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