Silicon photonics holds the promise of converging electronics and photonics. The key component, a low-cost high-performance laser, is still missing however within this platform. Although novel solutions have been proposed to increase the light emission directly from silicon (or Ge), compared with their III-V counterparts [1-2], these solutions are still in their infancy. Recently, the epitaxial growth of III-Vs on silicon regained a wide interest. III-V nanowire growth has been widely investigated. However, most of the III-V nanowire lasers on silicon require a complex cleaving and transfer process, which make these devices not suitable for dense integration [3]. In addition, the large cavity dimensions along the nanowire axis (several microns) hinder dense integration. Here, we present the first room-temperature operation of an ultra-short InP nanowire laser that is epitaxially grown on an exactly [001] oriented silicon substrate. The sub-micron sized laser cavity largely enhances the interaction of the lasing mode with the gain medium, and a large spontaneous emission factor has been obtained.

To obtain these results, we developed a unique epitaxial process which enlarges the lateral dimensions of a defect-free InP/Si nanowire such that it can sustain high quality optical modes. As shown in Fig.1, as the first step, holes of 100 nm diameter are defined in a SiO₂ mask to expose the silicon surface. After depositing and annealing a layer of Ge, epitaxial growth of InP was carried out in a metal organic chemical vapor deposition (MOCVD) reactor. The defect necking effect [4] of the narrow holes blocks propagation of the dislocations from the lattice-mismatched interface and defect-free InP is obtained at the mask surface. On this virtual lattice matched substrate, InP nanowires are grown along the [111] direction. Lateral overgrowth of InP on the SiO₂ mask took place right after the beginning of the nanowire growth, therefore the dimension of the formed nanowire cavity is much larger than the SiO₂ hole. The insert of Fig. 1 shows a 45° titled scanning electron microscope (SEM) picture of a typical InP nanowire on silicon. The length of the nanowire cavity is only 700 nm.
Thanks to the limited dimensions of the SiO2 hole that connects the cavity and the substrate, the downwards leakage loss is low enough to permit room-temperature laser oscillation. A Nd:YAG laser with 7 nanoseconds pulsed output is used as the optical pump source. Fig.2(a) shows the light in-light out (L-L) curve measured in a photoluminescence (PL) setup. The PL spectrum recorded above threshold is also shown in the insert. The clear slope transition in the L-L curve is a strong signature of threshold behavior. By applying a classic rate equation fitting process, a large spontaneous factor of 0.1 is obtained, which indicates very compact optical confinement. In order to identify the optical mode that oscillates in the short nanowire cavity, a finite-difference time-domain (FDTD) based numerical tool (Lumerical) was used, and the simulated optical mode distributions are plotted in Fig.2(b) and (c). As one can expect, regular Fabry-Perot modes, which are found in most of the demonstrated nanowire lasers, cannot oscillate in this cavity due to the irregular bottom contact with the substrate. Instead, a helically propagating cavity mode with hexagonal whispering gallery-like mode pattern in the transverse plane is found by simulations [5]. Its insensitivity to the bottom contact helps to maintain a relative high-Q factor for the lasing mode (~400 in this case). The asymmetrical mode profile shown in Fig.2(c) is mainly caused by the presence of the InP-filled SiO2 trench at the bottom.

In conclusion, an ultra-short InP nanowire laser with compact mode size was epitaxially grown on a (001) silicon substrate. Optically pumped room-temperature lasing was achieved. This monolithic integrated micro-laser is very promising for applications that require high integration density.

Acknowledgement:
We acknowledge support from the EU through the ERC-starting grant ULPPIC.

References: