# Optically integrated InP-$Si_3N_4$ hybrid laser

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Abstract—We present the first demonstration of an optically integrated InP-$Si_3N_4$ hybrid laser. The feasibility and viability of facet-to-facet, butt-coupled integration is proven by single-frequency operation, tunability across a wide range of 43 nm (including the entire telecom C-band) with spectral linewidths as narrow as 87 kHz.

## I. Introduction

Narrow linewidth semiconductor lasers are of interest for a wide range of applications [1], [2]. Specifically when looking for narrow spectral linewidths, monolithic semiconductor lasers in which all the components are made of the same material approach their limits. This is the reason why so-called hybrid lasers are currently receiving considerable interest. In such lasers, the semiconductor amplifier is optically coupled to a low-loss waveguide circuit made from another material, and this is known to decrease the Schawlow-Townes linewidth of a laser [3]. In this paper, we demonstrate an optically integrated InP-$Si_3N_4$ laser for the first time. For providing a strong margin of tolerable losses and cavity designs, we utilize a high-gain reflective semiconductor optical amplifier (RSOA).

## 2. Integration processes

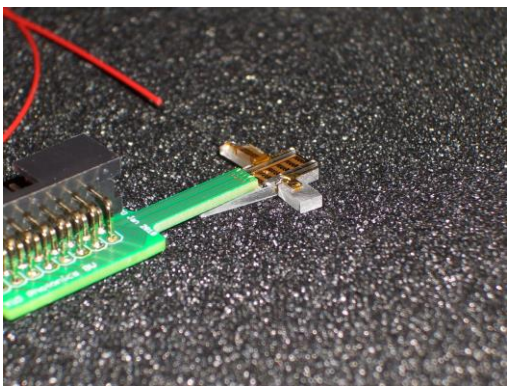

**Fig. 1. Photograph of the integrated hybrid laser**

A picture of the integrated laser is shown in Fig. 1. The RSOA and the feedback circuit were fixed on separate submounts and all the electric contact pads were wire-bonded to a fan-out printed circuit board (PCB) which was connected to a dedicated designed controlling board. The output waveguide facet was first aligned and assembled with a high numerical aperture (NA) polarization maintaining (PM) fiber that has a specified 1/e field strength mode field diameter (MFD) of 6 μm in both directions to minimize the output coupling loss. Optically transparent UV curable adhesive was applied to the InP-$Si_3N_4$ interface. After fiber-chip assembly, the InP section and $Si_3N_4$ circuit were aligned using translational stages under monitoring of the output power and optical spectrum until the glue was cured by UV light. Afterwards, the whole laser was mounted on top of a copper heat sink using thermally conductive silver-filled epoxy.

## 3. Characteristics of the integrated hybrid laser and discussion

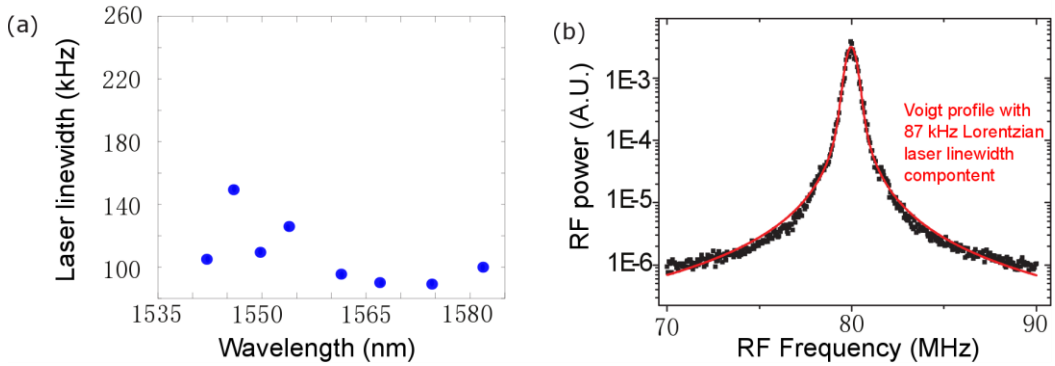


**Fig. 2. (a) Laser linewidth measured at various wavelength within the tuning range; (b) Recorded beat signal (black) at a driving current of 196 mA and a laser output wavelength of 1578.12 nm**

The fiber-coupled output power of the laser is about 1.7 mW at a 200 mA pump current at a threshold current of 35 mA. A first step of spectral characterization was thermo-optic wavelength tuning of the single-frequency laser output. A wide tuning range of 43 nm was achieved by thermally tuning the MRRs. The typical side mode suppression ratio (SMSR) ranges from 35 dB to 40 dB over the 43 nm tuning range and the relative intensity noise (RIN) is measured to be -135 dBc/Hz. Next we systematically measured the linewidths at various laser wavelengths as is shown in Fig. 2, while the output power was kept to around 1 mW,. The measurements clearly indicate that the laser exhibits linewidths smaller than 150 kHz over the entire tuning range, and exhibit a narrowest linewidth of 87 kHz.

Bearing in mind that the linewidth is inversely proportional to the output power [6] and also drops with the optical length of the external waveguide feedback circuit and its frequency selectivity, we expect that the laser linewidth can be reduced by a factor of 10 straightforwardly.

## 4. Conclusion

In this paper, an optically integrated InP-$Si_3N_4$ hybrid laser is presented for the first time. A wide range operation of more than 43 nm is achieved with a typical side mode suppression ratio (SMSR) of 35 dB. The laser shows good noise performance with relative intensity noise less than -135 dBc/Hz and a very narrow linewidth as low as 87 kHz. Such properties make InP-$Si_3N_4$ hybrid lasers promising for advanced quadrature amplitude modulation (QAM) [1].

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