Intensity noise and nonlinear properties of a hybrid plasmonic distributed feedback laser

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***Abstract*—Intensity and nonlinear properties of a hybrid plasmonic distributed feedback laser is reported. Interestingly, it is found that this laser exhibits a larger oscillation regime under optical feedback along with a sharper intensity noise response.**

Keywords—Surface plasmon, distributed feedback laser, optical feedback

I. Introduction

Surface plasmon polaritons (SPPs) are an electromagnetic wave mode produced by the interaction of light and free electrons on a metal surface that is limited near the metal-dielectric interface and can provide an increased near field. The effect of surface plasmon polaritons enables laser photons to be generated in sub-wavelength size space. This property makes it a potential candidate for photonic integrated circuit (PIC) chips, which can perform ultra-fast signal processing [1]. While plasmonic loss is an obstacle in the path of industrial applications of plasmonic lasers, multiple loss-reduction methods have been proposed [2, 3], leading to the perspective of PIC systems integrating plasmonic lasers as on-chip sources. On the other hand, it is important on this stage to evaluate the stability of such kind of laser source against external optical reflections, which are considered as a severe issue for PIC applications due to manifold interfaces or transitions between layouts and between components on PIC chips. In this work, we investigate static, relative intensity noise (RIN) and nonlinear dynamics of a hybrid plasmonic quantum well (QW) distributed feedback (DFB) laser. In particular, feedback experiments unveil that, comparing to a conventional QW DFB laser, the plasmonic device exhibits a similar reflection sensitivity, however the route to chaos is composed of a sustained periodic oscillation regime that widely expands over 13 dB from the onset of the destabilization. These results bring new insights on the nonlinear dynamics of hybrid plasmonic QW DFB lasers hence providing guidelines regarding their functionalities for novel integrated applications.

II. Experiments and Results

The plasmonic DFB laser consists of an active region made with nine tensile-strained InGaAlAs QWs and thin metal fingers wrapped with gratings on an InP substrate. Metallic fingers coating lays on top of the active region, consisting of the grating that diffracts the light and couples with the SPPs, as shown in Fig. 1(a). Semiconductor lasers for telecommunications typically operate in transverse electric (TE) polarization owing to tensile strained QW. However, a transverse magnetic (TM) polarization can also be obtained thanks to the strain. SPPs are transverse magnetic (TM) polarized, therefore strained QWs represent an excellent candidate as gain material for surface plasmon amplification. Here, the hybrid mode stems from the coupling between a classical TM polarized mode guided within the active region by the dielectric claddings and a surface plasmon mode guided at the interface between the upper cladding and the top metal contact of the device. More details regarding the laser structure are available in [4].

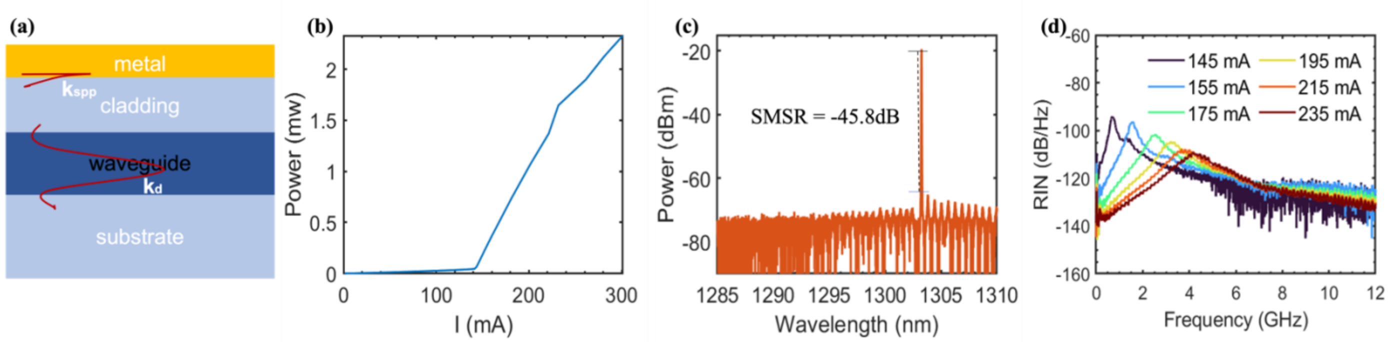

Figure 1. (a) Schematic of the hybrid plasmonic QW DFB laser structure; (b) Power-current characteristics at 288 K; (c) Optical spectrum under twice threshold current at 288 K; (d) RIN spectra at different bias currents at 288 K.

Fig. 1(b) shows the light current characteristics at 288 K where the threshold current (I_{th}) is around 147 mA. Fig. 1(c) displays the optical spectrum of this device at $2\times I_{th}$, the lasing mode is around 1303 nm within the telecommunication band and with a side mode suppression ratio (SMSR) exceeding 45 dB indicating that the laser is perfectly single mode. Fig. 1(d) depicts the RIN spectra at 288 K under different bias current ranging from 145 to 235 mA. The relaxation oscillation frequency (ROF) increases from 0.8 GHz to 4.2 GHz with the bias current. Besides, the RIN spectrum gradually decreases down to the minimum value below -135 dB/Hz in the range from 10 GHz to 12 GHz, above threshold current. Interestingly, the relaxation oscillation peak appears much sharper than in standard QW DFB lasers made with dielectric waveguide. This effect needs to be further investigated but it may be attributed to the additional contribution from the surface plasmon wave which leads to a lower damping during the laser operation.

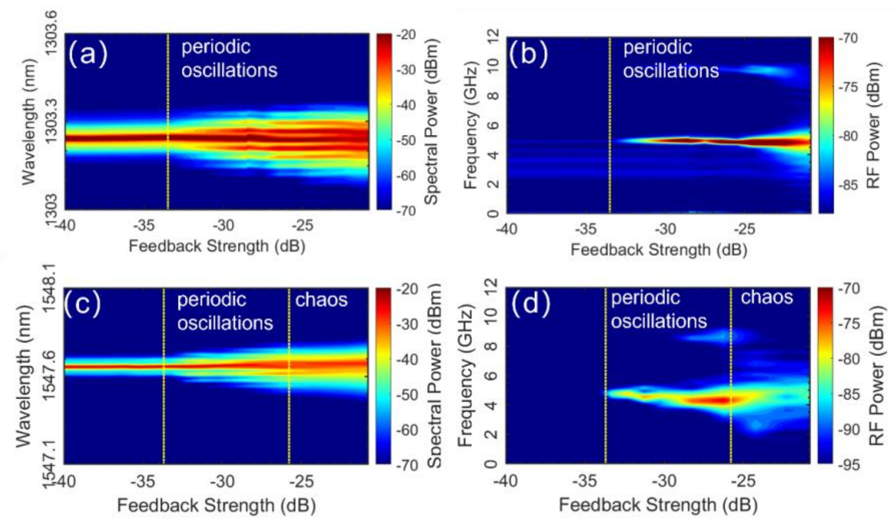

Figure 2. (a) Optical spectral maps for hybrid plasmonic QW DFB laser and (c) dielectric based QW DFB laser; RF spectral maps for (b) hybrid plasmonic QW DFB laser and (d) dielectric based QW DFB laser. Both lasers are biased at $2\times I_{th}$.

Based on a fiberized setup that includes a 10-meter-long external cavity, optical and RF spectra are measured for different optical feedback strength (r_{ext}) ranging from -40 to -21 dB. Fig. 2(a) and 2(c) show the optical spectral mapping for both the hybrid plasmonic QW DFB laser and the conventional QW DFB laser [5] as a function of optical feedback strength at twice threshold current, while the corresponding RF spectral maps are represented in 2(b) and 2(d). The destabilization process in both lasers starts at a feedback strength close to -34 dB. As expected from the theory, it begins with the undamping of ROF which develops into a periodic regime. In the optical domain, the lasing mode splits into multiple peaks, while in the RF domain, feedback induced oscillation rises from the ROF. In Fig. 2(c) and 2(d), such periodic regime evolve into chaotic oscillations with highly broadened optical mode as the feedback strength increases. This nonlinear feature corresponds to the traditional route-to-chaos in a standard QW DFB laser whereby fully developed chaos can be observed. On the other hand, in the case of the hybrid plasmonic QW DFB laser, only periodic oscillations occur, in other words, the periodic regime expands over 13 dB from the onset of the destabilization (r_{ext}= -34 dB), which is highly visible in the RF domain from the ROF contribution peaking at 5 GHz. Although the origin of such a phenomenon is not completely understood yet, the major contributing factor on this stage can be attributed to the lowered damping effect by the surface plasmon waveguide, as aforementioned.

III. SUMMARY

In this work, we studied intensity noise and nonlinear properties of a hybrid plasmonic QW DFB laser operating in the telecommunication band. We found that the relaxation oscillation in the RIN spectrum is much sharper than in standard QW DFB lasers which is attributed to the surface plasmon wave. In presence of optical feedback, experiments demonstrated that, compared to a standard QW DFB device, the plasmonic one exhibits a much wider window of periodic oscillations. Such behavior can be further exploited for novel applications such as photonic microwave generation, radio-over-fiber communication, and laser Doppler velocimeter.

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