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DESIGN AND INVESTIGATION OF A LOW-THRESHOLD ORGANIC LASER DIODE USING MIXED-ORDER DFB CAVITIES

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Abstract. In this work, we experimentally and theoretically investigate the optical and electrical optimization of an OLED associated to a mixed-order DFB cavity. We, firstly focus on the design and the fabrication of a mixed-order DFB cavity with a high quality factor. We particularly study the impact of the deposition of the organic layers on the topology and the quality factor of the cavity.

1 Introduction

Organic semiconducting materials have a growing interest in the field of photonics. Thanks to their outstanding features in terms of low-cost fabrication, easy processing, chemical versatility, and wavelength tunability across the entire visible range[1], significant research efforts have been made in the last two decades to use them in optically and electrically pumped solid-state laser. However, one of the most important challenge in the field still the realization of organic laser diodes under electrical pumping. Besides, the race actually concerns the development of organic laser diode (OLD) based the utilization of organic light-emitting diode (OLED) with a resonant cavity[3]. For instance, several reports have shown significant interest in the study of new molecules with a high net gain[2]. Sub-nanosecond pulse pumping seems to be emerging as an alternative to avoid the accumulation of non-radiative triplet excitons[4]. Moreover, the realization of a resonant cavity with a high quality factor (Q-factor) compatible with the OLED structure and the electrical pumping scheme is very challenging[6].

Regarding the gain of the standard organic molecules, recent studies predict that the laser threshold would be reached in cavities with Q-factors of the order of a few thousand[5]. Today, the architecture, which has made it possible to have the lowest laser threshold under optical pumping (35nj/cm²) is the mixed-order distributed feedback cavity (DFB)[7]. It allows a strong coupling between the light and the amplifying medium, while providing a large surface area available for radiative recombination. This mixed-order DFB cavity consists of two gratings: the first-order grating allows the confinement of light inside the cavity and the second-order grating is used for extracting light *via* a diffractive mode, orthogonal to the cavity. Recent work has shown a laser effect under electrical pumping by using a promising organic molecule (BSBCz), with a threshold of 600A/cm²[7]. Nevertheless, several questions are still to be considered. In particular, the optimal geometry of such a cavity (topology and dimension of the cavity) and the Q-factor which, could be actually obtained and the optimization of the grating coupling coefficient κ^3 for a homogeneous distribution of the field in the cavity[8]. In addition to that, the deposition of the OLED hetero-structure induces a tilting of the sides of the gratings. Thus, it is important to study the impact of this topological modification on the coupling coefficient.

In this work, we report the theoretical and experimental study of the optical and electrical optimization of an OLED associated to a mixed-order DFB (Distributed FeedBack) cavity. We, particularly, focus on the optimization of the optical resonator in order to obtain the most suitable cavity for our applications.

2 Results and discussion

In this context, we, firstly, performed several simulations by using the FDTD method. For example, our results give us a first approximation of the most optimal cavity length for a homogeneous field distribution. We calculate the quality factor from the resonance wavelength of the cavity shown in figure 1. It gives us a Q ~1000 for a cavity length of 20 µm for order 1 on both sides. This result seems comparable with Adachi's work [7].

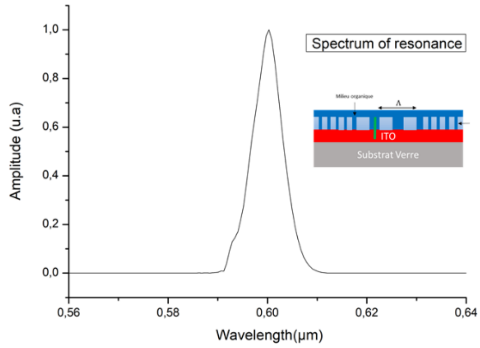

Figure 1: Resonance spectrum of the diffracted wavelength of mixed order DFB cavity using FDTD solution

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As an example, the micro-cavity fabricated and studied in this work is shown in Fig 1a. It consists of the implementation of the structure by using electronic lithography in a HSQ resin. The next step will concern the deposition of the organic hetero-structure by thermal evaporation on the top to the obtained DFB structures as displayed on Fig 1b.

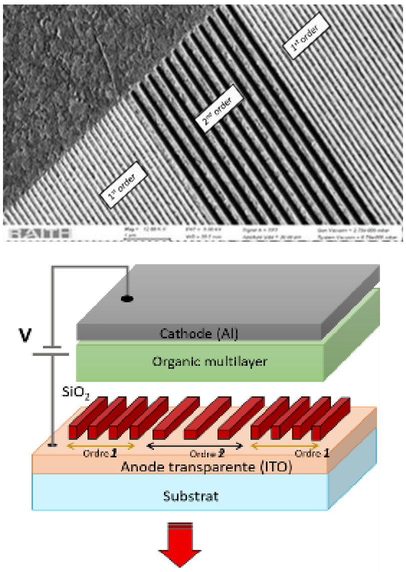

Figure 2: a) SEM image of a mixed-order DFB structure, and b) Schematic representation of the OLED in cavity

Comparing to the mixed-order cavities presented in the literature[6,7], we do not use an etching step which, avoid damaging of the underlying layers. In addition, the use of this process would allow us to substitute the ITO electrode with a graphene layer[9] or a dielectric/metal/dielectric multilayer[10] which is more favorable for the optical confinement of the light in the cavity.
Afterward, we will study the spectral response of our cavities relying on a technique based on a double monochromator experimental setup (Fig 2).

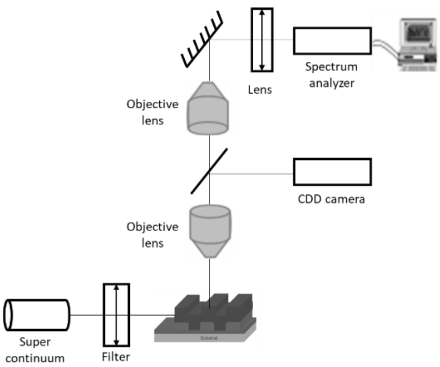

Figure 3 : Experimental setup for the measurement of the spectral response of the cavity

As shown, the spectrum collection system consists of two optical channels, one of which is dedicated to the observation of structures and the other to signal detection. It consists of, pumping our samples with a precise wavelength with a super Continium coupled to a monochromator and, collecting the cavity response by using another monochromator coupled to a CDD camera.

During the conference, we will present the obtained results, compare them to the devices developed by other competing teams[9,12].

3 Conclusion

In this paper, we focus on the optimal design of DFB resonators to be used with organic materials for laser effect. FDTD simulations and the corresponding experimental results will be presented and discussed, in particular through the use of a characterization setup aimed at measuring the spectral response of our cavities.

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