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Structural Characterization of Multi-Quantum Wells in Electroabsorption-Modulated Lasers by using Synchrotron Radiation Micrometer-Beams

By *Lorenzo Mino, Diego Gianolio, Giovanni Agostini, Andrea Piovano, Marco Truccato, Angelo Agostino, Stefano Cagliero, Gema Martinez-Criado, Simone Codato,* and *Carlo Lamberti**

Advanced optoelectronic devices, the backbone of modern communication technology, require the monolithic integration of different functions at chip level. An example of devices fulfilling this requirement are multi-quantum well (MQW) electro-absorption-modulated lasers (EMLs) employed in long-distance, high-frequency optical fiber communications technology. Such devices are realized by using the selective area growth (SAG) technique. Optimization of the growth parameters is carried out by empirical approaches as direct structural characterization of the MQW is not possible with laboratory X-ray sources, owing to the micrometer-variation of composition and thickness inherent to the SAG technique. Micrometer-resolved X-ray (μ-X-ray) beam available at third generation synchrotron radiation sources, such as the ID22 at the European Synchrotron Radiation Facility (ESRF), allowed us to directly measure the determinant structural parameters of MQW EML structures such as well and barrier widths and mismatches with a 2 μm spatial resolution.

In more detail, optoelectronic devices, widely used in the generation and detection of optical signal for telecom and datacom applications, consist of different III-V semiconductors alloys deposited on suitable substrates. The deposition can be performed by different techniques that are based on the crystal rebuilding of a semiconductor used as substrate, such as metal organic vapor phase epitaxy (MOVPE).[1,2] The reaction takes place between free atoms and the substrate's surface with the rebuilding of the crystal lattice. During the growth different layers are sequentially and uniformly deposited on the entire substrate, resulting in the aimed structure relative to the specific device function (e.g., LED, laser, amplifier, modulator, photodiode, waveguide, etc.).

As an example, uncooled distributed feedback (DFB) lasers, operating in the second window of telecommunications at 1310 nm, are MQW semiconductor lasers directly modulated at high frequency (up to 10 Gb s^{-1}) and are a key element for connections typically up to 10 km. For longer distances a directly modulated laser cannot be used. The devices operate at 1550 nm (third-window) to take advantage of the limited fiber attenuation. However, in the presence of chromatic-dispersion on a standard single-mode fiber at this wavelength, the high positive chirp[3] of the optical pulses, generated by directly modulated DFB, severely limits the propagation span (~10 km at 10 Gb s^{-1}). For 40–80 km propagation of 10 Gb s^{-1} optical signals, external modulation is needed. An external MQW electroabsorption modulator (EAM) can produce near-zero or even negatively chirped pulses, allowing propagation spans of more than 80 km. An EML,[4,5] obtained by monolithic integration of an EAM with a constant-injected DFB laser (Fig. 1b), is often the most convenient and compact solution. The modulation of the laser emission is ensured by the switching between an opaque and transparent state of the EAM due to the Stark effect[6] (Fig. 1c) induced by a voltage modulation in the 10 GHz domain.

In order to reduce cost, size, and power consumption, the modern optoelectronic devices operate at very high temperature (80 °C and above) without coolers. The design of MQW band structure is the key parameter for optimizing the performance. In particular, for an EML, high extinction ratio, low insertion loss, negative chirp at 1550 nm, and high temperature operation are fundamental parameters.[7,8] This means that deep knowledge on the structure of both EAM and DFB MQWs is essential and our work will be focused on the characterization of the semiconductor material constituents of the EML device.

In the past, the integration of the two functions was realized by an external connection between discrete devices. The drawback of this approach was the relatively low efficiency of the coupling, resulting in a high fraction of photon loss at the DFB/EAM interface, high dimensions of the final device, high sensitivity to temperature, and high cost. Over the last decade, many research efforts were devoted to the development of reliable monolithic

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[*] Prof. C. Lamberti, L. Mino, D. Gianolio, Dr. G. Agostini, A. Piovano
Department of Inorganic, Physical, Materials Chemistry
NIS Center of Excellence and INSTM Unit, University of Turin
Via P. Giuria 7, 10125 Turin (Italy)
E-mail: carlo.lamberti@unito.it

Dr. M. Truccato
NIS Center of Excellence, Department of Experimental Physics, University of Turin
Via P. Giuria 1, 10125, Turin (Italy)

Dr. A. Agostino, Dr. S. Cagliero
NIS Center of Excellence, Department of General and Organic Chemistry
University of Turin
C.so Massimo D'Azeglio 48, 10125, Turin (Italy)

G. Martinez-Criado
ESRF
6 rue Jules Horowitz, BP220, 38043, Grenoble CEDEX (France)

S. Codato
Avago Technologies Italy S.r.l., Torino Technology Centre
Via G. Schiaparelli 12, 10148 Turin (Italy)

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