LOCALIZING CHEMICAL AND BIOLOGICAL THREAT DETECTION

Detection Of Dimethyl Methylphosphonate (DMMP) With An Interband Cascade Laser Sensor

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On-chip chemical sensing systems operating in the midwave infrared (MWIR) “fingerprint” region are expected to find broad applicability in trace chemical detection by exploiting ultra-compactness and minimal operational power for long battery lifetimes [1]. However, it is quite challenging for an on-chip device to detect hazardous chemicals in gases or vapors, due to low gas phase concentration in the atmosphere and small spatial overlap with optical modes mode propagating in a semiconductor waveguide. Here we report the parts per billion (ppb) detection of dimethyl methylphosphonate (DMMP), a nerve-agent simulant, by employing a sorbent layer (HCSFA2 & oapBPAF) that enhances the DMMP interaction with the gain mode in an interband cascade laser (ICL) [2] as shown in Fig.1.

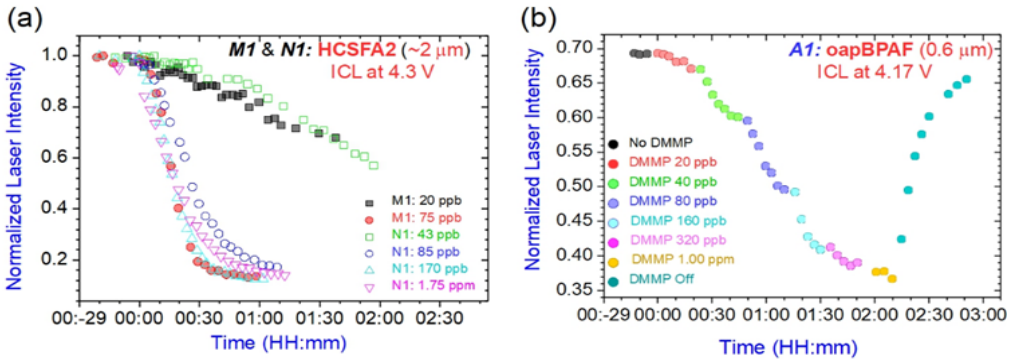

Fig. 1. Time-dependent decrease of the normalized laser output (InSb detector response) at fixed ICL bias voltage near threshold during the flow of DMMP: (a) Device M1 (coated with a 2-mm-thick layer of HCSFA2, solid points) for two DMMP concentrations and Device N1 (nominally identical coating, open points) for 6 concentrations. (b) Device A1 (oabBPAF 0.6 mm) at DMMP concentrations ranging from 20 ppb to 1 ppm successively higher concentrations over a period of two hours, followed by recovery after termination of the DMMP flow.

This was achieved by replacing the ICL’s top cladding layer with a thin coating of a HB acidic sorbent, in this case oapBPAF [3], but which can be catered to any class of analyte. This functionalized sorbent provides strong absorption at low DMMP concentrations in air. Although the present experiments employed an off-chip InSb detector to monitor the output from the ICL’s end facet, on-chip interband cascade detectors formed by reverse biasing the ICL gain stages outside of the laser cavity can be incorporated in future work to perform the detection process in an integrated, monolithic fashion. Alternatively, a sufficient sensitivity to internal loss contributed by analyte molecules captured by the sorbent coating may be attained simply by monitoring the differential I-V characteristics near threshold, which would eliminate the dedicated detector entirely. By confining the entire sensor package to a single chip (plus drive electronics), the size, weight, power, and cost (SWaPc) of the resulting system can be extremely low. For example, a cw ICL with sorbent-coated sensing window could be powered by batteries, and ultimately operate with drive power < 200 mW for a sensing laser plus reference laser. This will be ideal for implementation on extremely small platforms such as wearable badges, micro-UAVs, or miniature robotic platforms that respond reversibly to chemical threats at concentrations relevant to DoD.

[1] J. R. Meyer, C. S. Kim, M. Kim, et al., “Interband Cascade Photonic Integrated Circuits on Native III-V Chip.”, Sensors 21, 599 (2021).
[2] I. Vurgaftman, R. Weih, M. Kamp, et al., J. Phys. D 48, 123001 (2015), “Interband Cascade Lasers.”
[3] CA Roberts and RA McGill, US Patent, 11,779,901 B2 (Oct. 10, 2023), “Bisphenol Hypersorbents for Enhanced Detection of, or Protection From, Hazardous Chemicals”.