Microfluidic Opportunities and Challenges in Security R&D

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• Background and Societal Impact
  – Definition of security
    • Homeland/defense security
    • Food/water security
    • Economic security
  – Where does microfluidic security fit in a security R&D portfolio?
    • Potential applications
    • Stages of development/technological maturity
    • Education and training
  – General overview of fluid mechanics and homeland security found in Settles¹

Number of microfluidic patents issued per year in the USA²
• Background and Societal Impact: Concept of **Dual-Benefit** Security Technology\(^3\)
  – Robust solutions require diversity of stakeholder involvement
  – Dual-benefit: Revision of earlier “dual-use” (defense-commercial strategy)
    • “Dual-use”: Larger market means lower unit cost
    • “Dual-benefit”: Benefits extend to all users, concurrent benefits to various missions
  – Examples
    • Sensors in food supply: Improved detection of accidental *or* intentional contamination
    • Hazardous chemical sensors: Improved response to industrial accident *or* terrorist event
• Focus on Microfluidic-specific Security Research
  – Primary application areas
    • Explosives detection
    • Chem/Bio detection
      – R&D on sensors with broad range of chem/bio agent detection capabilities cited as major need by committee in 2002 NRC report on National Security & Homeland Defense (along with sensor miniaturization)
    • On-site medical diagnostics
  – Secondary application areas
    • Microfluidic components for systems-level integration
• Technical Principles: Potential Advantages
  – Portability
    • Some current bio-agent detection military devices require transport/power via “high-mobility multiwheeled vehicles” (HMMWV)\(^5\)
  – Response time
  – Automation\(^6\)
• State-of-the-Art (Example I): Explosives Detection
  – Sandia national labs\textsuperscript{7}
    • Portable, self-contained system
    • Focused especially on detecting nitroaromatic explosives in environmental samples
  – Others reviewed in Wang\textsuperscript{8}:
    • Detect both nitroaromatics and explosive-related ions\textsuperscript{9}
    • Micro-cantilever-based detection of plastic explosives\textsuperscript{10}

\begin{center}
\mu\text{ChemLab} prototype and indirect LIF detection system (microfabricated) in Sandia’s\textsuperscript{6} \mu\text{ChemLab} explosives analyzer\textsuperscript{7}
\end{center}
• **State-of-the-Art (Example II): Nerve Agent Detection**
  – Volatile G-type: Includes sarin
  – Less volatile V-type: Includes VX
  – Can use CE analysis (incorporate in mobile lab)
  – Lab-on-a-chip (LOC) nerve agent detection technology yet immature, but under development
    • Detection limits: 50 µg/L
    • No demonstrated on-chip analysis of real environmental sample
    • Development focuses on integration of sampling and sample prep subsystems on-chip, sensitivity improvement of detection
• State-of-the-Art (Example III): Single Virus Detection\textsuperscript{12}
  • Viruses can act as agents for biowarfare and terrorism
  • Established methods can require larger amount of sample (inconvenient)
  – Lieber’s group: Use semiconducting nanowires configured as FET
    • Detected single-viruses of influenza A
    • Potential for large-scale integration/concurrent detection of multiple distinct viral threats

\textsuperscript{12} Conductance-based single virus detection
State-of-the-Art (Example IV): Secondary Components Required for Chip-Level Integration

- Pumps
  - Pressure-driven, electrokinetic
- Valves
- Multiphase-flow-based concepts
  - Droplet/bubble manipulation for production of particles, emulsions, foams or as mini-reactors

Fig. 5 Control of concentration in droplets by fission mechanism. Droplets are generated with a dye to water volume ratio of 1:2 inside the droplet (left). After the mother droplet breaks in succession at the three bifurcating points, each stream of daughter droplets contained different final fractions of the original dye concentration (right).

Concentration control in droplets

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• Barriers
  – Diverse detection requirements
    • Diverse molecular nature of bio/chem agents
    • Difficult to develop general-purpose detector
    • High specificity, sensitivity imperative
  – Sample preparation/handling
    • Contaminated substances have complex make-up (e.g. soil, blood, feces)
    • On-chip pumping, valving, reagant storage not yet at level for integration into non-expert user systems
• Barriers
  – Integration
    • Small-scale
    • Very-large scale
  – Stage of Development\textsuperscript{14}
    • “Early adolescence”
    • Technology revolution requires broad range of components/subsystems plus integration into systems for non-expert users
    • Killer app not yet emerged?

Schematic of very-large scale integrated sensor network\textsuperscript{5}
• **Recommendations**

  1. Pursue “dual-benefit” R&D (security and other)
  2. Maintain balanced basic and applied R&D portfolio within federal government as a whole
  3. Encourage interdisciplinary and academic-industry collaborations
  4. Pursue balanced R&D portfolio in terms of analytical components and components required for small- and large-scale integration
References


References


References


