crystals

MDPI

Editorial

Challenges and Opportunities for Nematic Liquid Crystals in Radio Frequency and Beyond

Jinfeng Li [1,2]

[1] Department of Electrical and Electronic Engineering, Imperial College London, London SW7 2AZ, UK; jinfeng.li@imperial.ac.uk or j.li@bangor.ac.uk
[2] Nuclear Futures Institute, School of Computer Science and Electronic Engineering, Bangor University, Bangor LL57 1UT, UK

Revving up the rollout of high-data-rate low-latency next-generation communication and beyond (5G and 6G), the trend of developing tunable components based on tunable dielectrics is feeding the appetite for precise beam steering and wavefront phase control with more reconfigurability and bandwidth, as well as power-efficient stepless controllability (continuous analogue tuning) for mission-critical systems.

Among tunable dielectrics, nematic liquid crystal (NLC) is a significant player and NLC based reconfigurable devices (e.g., phase shifters, filters) at microwave frequencies have been extensively studied and optimised in the last two decades. New challenges and opportunities are evolving from microwave (MW) [1] with proven performance in millimetre-wave (mm-Wave) [2] and terahertz (THz) [3] frequencies pending further demonstrations.

For the less explored wavelength range from mm-Wave to THz for 5G and 6G, excessive insertion loss and response time are among the most commonly cited challenges. Compounding the issue, apart from the pursuit of high tuning ranges and low insertion losses, complex challenges come with size miniaturisation, high thermal stability, and high reliability, for which legacy device configurations struggle to meet the more stringent high-performance requirement. Re-evaluating the effectiveness of conventionally employed metrics (such as figure-of-merits), it is advisable from [4] that seeking to formulate a unified metric that can be used to compare states of the arts is another ongoing commitment to boost the NLC development.

Integration and miniaturisation can be enabled by using high permittivity substrate materials (ceramics) to reduce the size of NLC-based devices. This will also drive an overall cut in insertion loss with an appreciable decline in dielectric dissipation (due to a reduced-volume NLC), albeit partially offset by an elevated metal loss.

Integrated RF packaging and shielding are also pivotal for NLC based devices' performance. The design of the surface mountable package is envisaged to be optimised without sacrificing in-band performance. Leveraging additive manufacturing with gold directly plated on devices' core functioning circuitry, nickel is expected to be only applied to the soldering region for a minimal dissipation.

Embracing THz challenges by NLC is at the infancy stage, such as THz optical modulators [5]. Promisingly, RF electronics is catching up fast. One of the future solutions to pursue is thus the photonics–electronics integration, with optical modulation, optical waveguide, and germanium photodiode on silicon. Whether such combinations with NLC can ever actually be produced with repeatable performance, however, is questionable. There remain challenges from prototype to high volume production and pick-and-place operation.

Looking further ahead, there is a high hurdle in scaling up NLC based systems for large antenna arrays outside the lab, such as the Square Kilometre Array (an intergovernmental radio telescope) [6]. On the other hand, there remains a gap (opportunity) in deploying NLC for small-scale dynamic beam-steering systems, such as gesture recognition micro-radars [7].

check for updates

Citation: Li, J. Challenges and Opportunities for Nematic Liquid Crystals in Radio Frequency and Beyond. *Crystals* **2022**, *12*, 632. https://doi.org/10.3390/cryst12050632

Received: 18 April 2022
Accepted: 27 April 2022
Published: 28 April 2022

Material innovation should keep on active momentum. Light sensitive materials with photoexcitation can be a speed booster for addressing the long-lasting slow response issue of NLC devices at RF, MW, and mmWave. While capturing the photo-chemical switching is an advantage to allowing optical addressable control, reducing the material mixture's heat dissipation (insertion loss) remains an open challenge.

Another challenge is the temperature stability of the NLC based devices for applications requiring low insertion loss as well as low insertion loss variation across a wide range of operating temperatures. RF test over temperature is arguably mandatory for not only serving industry, but also upgrading academic research-grade prototypes.

Developing a standalone simulator platform that combines NLC director modelling with RF full-wave simulation in a single stage will be highly desirable. Furthermore, in the quest for high-fidelity simulators with enhanced reliability and design flexibility, experimental characterisation techniques and facilities should keep up to date for more and more refined simulation models as verified by measurements.

With the convergence of the above advancements taking place, building up an expansive portfolio of in-stock (ready-to-ship) NLC based RF components will become a strategic need. To fit varied industry needs, there is a wide variety of unexplored reconfigurable components that can be highly engineered with NLC, such as variable attenuators, tunable gain equalizers, tunable switch filter banks, tunable couplers, tunable power dividers, tunable bias networks (bias decoupling, bias filtering), tunable resonators, frequency synthesizers, etc.

What this editorial has mentioned and foreseen may well be just the tip of the iceberg, but how close the next-generation communications and instrumentation are transforming with NLC is written in the stars. Harnessing the emerging technological arms race globally, dozens of companies and research institutes will set out to make an affordable crossover, thus laying the path for mass production to happen.

Funding: This research received no external funding.

Acknowledgments: The Guest Editor is grateful for the contributions from all the submission authors (though some papers are rejected due to a lack of novelty) and reviewers. Ongoing submissions are welcome prior to the upcoming deadline.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Maune, H. Microwave Liquid Crystal Technology. *Crystals* **2020**, *10*, 716. [CrossRef]
2. Li, J.; Chu, D. Liquid Crystal-Based Enclosed Coplanar Waveguide Phase Shifter for 54–66 GHz Applications. *Crystals* **2019**, *9*, 650. [CrossRef]
3. Li, X.; Tan, N.; Pivnenko, M.; Sibik, J.; Zeitler, J.A.; Chu, D. High-birefringence nematic liquid crystal for broadband THz applications. *Liq. Cryst.* **2016**, *43*, 955–962. [CrossRef]
4. Li, J. Rethinking Figure-of-Merits of Liquid Crystals Shielded Coplanar Waveguide Phase Shifters at 60 GHz. *J. Multidiscip. Res.* **2021**, *4*, 444–451. [CrossRef]
5. Buchnev, O.; Podoliak, N.; Kaltenecker, K.; Walther, M.; Fedotov, V.A. Metasurface-based optical liquid crystal cell as an ultrathin spatial phase modulator for THz applications. *ACS Photon.* **2020**, *7*, 3199–3206. [CrossRef]
6. Farnes, J.; Mort, B.; Dulwich, F.; Salvini, S.; Armour, W. Science Pipelines for the Square Kilometre Array. *Galaxies* **2018**, *6*, 120. [CrossRef]
7. Ahmed, S.; Kallu, K.D.; Ahmed, S.; Cho, S.H. Hand Gestures Recognition Using Radar Sensors for Human-Computer-Interaction: A Review. *Remote Sens.* **2021**, *13*, 527. [CrossRef]