Jonathan Breeze

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Research Interests

Room Temperature Masers – Solid state masers were confined to operate at liquid helium temperatures due to rapid spin-lattice relaxation until 2012, when the discovery of pulsed masing in photoexcited pentacene meant that room-temperature operation was possible. Since then, I have conducted research in this nascent field and have recently demonstrated continuous-wave masing using diamond NV spin-defects.

Cavity Quantum Electrodynamics – Development of maser theory using aspects of quantum optics and open quantum systems led to the observation of strong-coupling and Dicke states at room-temperature in a pentacene/strontium titanate maser. Cavity QED plays a central role in describing the macroscopic quantum coherence of strongly-coupled spin-ensembles and high Purcell factor cavities.

Spin Resonance – Electron paramagnetic resonance spectroscopy has been key to understanding and characterising spin-triplets in candidate organic (pentacene) and inorganic (diamond) maser media. Currently working on expanding this work to include optically detected magnetic resonance and cavities for realising ultra-strong coupling in magnon-photon systems.

Employment

2007 – 2018 **Research Fellow**
Department of Materials, Imperial College London, London, UK.
- *Co-inventor of room-temperature maser*
- *Lead researcher on Maser Project*
- *Established research programme on diamond NV-centres as room-temperature gain media*
- *Room-temperature benchtop quantum cavity electrodynamics*
- *Ultra-high Q-factor and high Purcell-factor resonators*

1999 – 2007 **Senior Research Fellow**
Centre for Physical Electronics and Materials, London South Bank University, London, UK.
- *Development of cryogenic apparatus for measuring dielectric properties of metal oxides*
- *Research into advanced microwave dielectric ceramics*
- *Development of codes for modelling dielectric-loaded cavity resonators*

1994 – 1999 **Senior Microwave Design Engineer**
Passive Microwave Group, Matra Marconi Space, Portsmouth and British Aerospace Space Systems Stevenage, UK (now Airbus Space).
- *Responsible Engineer for passive microwave components for multi-satellite constellation*
- *Research and Development into high temperature superconductors and advanced ceramics for microwave equipment*

1993 – 1994 **Scientific Officer**
Centre for Basic Metrology, Division of Quantum Metrology, National Physical Laboratory, Teddington, UK.
- *Development of superconducting sapphire resonator for secondary frequency standards*

Education

2008 – 2014 (part time) **PhD,** *Centre for Physical Electronics and Materials, London South Bank University, UK.* **“Temperature and Frequency Dependence of Complex Permittivity in Metal Oxide Dielectrics: Theory, Modelling and Measurement”**. Springer Thesis Award 2015.

1990 – 1993 **BSc (Hons) Physics with Astrophysics,** *University of Leeds, UK.*

1984 – 1990 **A Levels**: Mathematics (A), Physics (A) and Chemistry (C), 9 GCSEs, 1 'O', 1 'AO' and 1 'AS' Level in Mathematics. Special Paper Physics (S1). *Ysgol–y–Creuddyn, Conwy, UK.*

Teaching

Lecturing part of Mathematics & Computing course MSE201 for 2nd year undergraduates in the Department of Materials, Imperial College. 2015-present. Responsible for setting/marking examination questions, attending examination boards and providing tutorial workshops.

Skills

RF/Microwave/optical design. Experienced in mathematical and computational modelling of passive electromagnetic structures such as filters, resonators, waveguides and antennae using mode matching techniques and finite-difference methods across the electromagnetic spectrum: from radio/microwave to optical (including nanophotonic/plasmonic devices). As well as using many self-written codes, the following commercial packages have been used extensively to model devices: Lumerical, CST Microwave Studio and COMSOL Multiphysics.

Numerical and computational skills. Significant expertise in computer programming, fluent in C/C++, Perl, Python, Matlab and Julia programming languages and specialism in numerical computation, OpenGL 3D graphics for visualisation, high-performance parallel computing (HPC) and GPU computing (CUDA). Experienced in mathematical packages Mathematica and Fortran.

Experimental techniques. I have many years of experience in designing microwave devices/experiments that operate at cryogenic temperatures. I designed a dielectric resonator system that could accurately measure the complex permittivity of materials in the range 10-320 K. This system was fully automated and used custom written GUI code interfaced with instrumentation. For the maser project, I developed a modular suite of Python drivers for interfacing with instrumentation (network analysers, magnetic field sensors/controllers, oscilloscopes, spectrum analysers *etc*). I am lab manager for the maser optics laboratory.

Materials modelling. As well as extensive experience in solid-state synthesis of metal oxide ceramics, I also have experience in materials modelling using density functional theory codes (Quantum-Espresso, CASTEP, Octopus, ORCA).

Engagement

Consultancy. I have provided consultancy services in the area of dielectric resonators and metamaterials for many companies including Comdev Europe, Microsulis, Antenova, Solartron, Ericsson, QinetiQ.

Awards and Memberships. Recipient of Springer Thesis Award 2015. Member of Institute of Physics.

Patents. I have two granted patents (UK/US) and have recently filed another:

- Granted in the US: "*Device and method for generating stimulated emission of microwave or radio frequency radiation*", Breeze & Alford, WO 2013175235A1, EP 2856582A1, US 9293890, US 20150103859.
- "*Temperature stabilisation of dielectric resonator*", Alford, Penn & Breeze, WO 2001042167A1, EP 1242337A1, US 6803132.
- Recently filed: "*Apparatus and method for establishing quantum oscillations*", Breeze, Kay & Salvadori. Application No. GB 1615645.7
- Recently filed: "*Room Temperature Masing using spin-defect centres*", Breeze et al. P46775GB.

Recent Publications (h-index 15)

L.V. Abdurakhimov *et al,* "*Strong coupling between magnons in a chiral magnetic insulator* Cu_2OSeO_3 *and microwave cavity photons*", (arXiv:1802.07113), Feb. 2018

J.D. Breeze *et al*, "*Continuous-wave room-temperature diamond maser*", Nature 555, 493–496 (2018).

J.D. Breeze *et al*, "*Room-temperature cavity quantum electrodynamics with strongly coupled Dicke states*", npj Quantum Information 3, No. 40 (2017).

J. Sathian, J.D. Breeze et al, "*Solid-state source of intense yellow light based on a Ce:YAG luminescent concentrator*", Optics Express 25, (2017).

E. Salvadori, J. Breeze *et al*, "*Nanosecond time-resolved characterization of a pentacene-based room-temperature MASER*", Scientific Reports 7 (2017).

J. Breeze, "*Temperature and Frequency Dependence of Complex Permittivity in Metal Oxide Dielectrics*", Springer, ISBN 978-3-319-44545-8 (2016).

S. Bogatko *et al*, "*Molecular Design of a Room-Temperature Maser*", Journal of Physical Chemistry C 120 (2016).

J. Breeze *et al*, "*Enhanced magnetic Purcell effect in room-temperature masers*", Nature Communications 6 (2015).

E. Donchev et al, "*The rectenna device: From theory to practice (a review)"*, MRS Energy & Sustainability-A Review Journal (2014).

M. Oxborrow, J.D. Breeze and N.McN. Alford, "*Room-temperature solid-state maser*", Nature, 488. (2012)

D.Y. Lei, S. Kena-Cohen *et al*, "*Spectroscopic ellipsometry as an optical probe of strain evolution in ferroelectric thin films*", Optics Express 20(3), (2012).
J. Breeze, M. Oxborrow and N. Alford, "*Better than Bragg: Optimizing the quality factor of resonators with aperiodic dielectric reflectors*", Appl. Phys. Lett. 99(11), (2011).

Selected Publications

1. "Continuous-wave room-temperature diamond maser"
J.D. Breeze, E. Salvadori, J. Sathian, N.McN. Alford, C.W.M. Kay, Nature 555, 493–496 (2018)
https://www.nature.com/articles/nature25970

The organic pentacene room-temperature masers are not amenable to operating continuously due to their long-lived lower spin-triplet sub-level and poor thermal properties. I decided to pursue an alternative maser gain medium, exploiting the optically-pumped spin polarizability, long spin-lattice and decoherence lifetimes of nitrogen-vacancy defects in diamond. Detailed modelling and previously developed cavity QED theory, predicted that a high Purcell-factor cavity was required. The successful realisation of continuous-wave masing reported in this paper is not only a milestone for the nascent room-temperature maser field, but also opens a new branch in the expansive field of diamond based quantum technologies.

2. "Room-temperature solid-state maser"
M. Oxborrow, J.D. Breeze and N. McN. Alford, *Nature*, 488(7411), pp. 353-356 (2012)
http://www.nature.com/nature/journal/v488/n7411/pdf/nature11339.pdf

Solid-state masers, invented in the 1950s were confined to operate at liquid helium temperatures due to fast spin-lattice relaxation of spin-polarized paramagnetic ions. This paper reported the first demonstration of a solid-state maser operating at room-temperature. The gain medium was a pentacene-doped *p*-terphenyl single-crystal located inside a ring of single-crystal sapphire. Photoexcitation of the pentacene molecules at 592 nm by a pulsed dye laser generated an inverted spin-triplet population whose zero-field-splitting of 1.45 GHz was resonant with the frequency of the cavity. The result was a maser oscillation burst that persisted for ~100 microseconds.

3. "Enhanced magnetic Purcell effect in room-temperature masers"
J. Breeze, K.-J. Tan, B. Richards, J. Sathian, M. Oxborrow and N. McN. Alford, *Nature Commun*. 6 (2015)
http://www.nature.com/articles/ncomms7215.pdf

The pentacene-based room-temperature maser was miniaturised significantly by using the high electrical permittivity of strontium titanate. A drastically reduced mode volume, $\sim(\lambda/20)^3$ and high *Q*-factor increased the Purcell factor by almost three orders of magnitude. The optical pump power threshold was reduced from ~ 230 W to ~ 2W, allowing maser action to be observed using a xenon flash-lamp as the optical source.

4. "Room-temperature cavity quantum electrodynamics with strongly coupled Dicke states"
J.D. Breeze, E. Salvadori, J. Sathian, N.McN. Alford, C.W.M. Kay, *npj Quantum Information* 3(40), (2017).
https://www.nature.com/articles/s41534-017-0041-3

This paper reported strong coupling at room-temperature in an improved pentacene/strontium titanate maser device. The dramatically reduced mode volume and an increase in the pentacene concentration within the *p*-terphenyl crystal produced an ensemble spin-photon coupling rate, that exceeded both the cavity decay rate and spin-mode decoherence rate, and which scaled as $\sqrt{N}$ with N being the number of excited pentacene molecules. Upon photo-exciting the pentacene molecules into inversion using nanosecond optical pulses, Rabi oscillations in the maser output power and normal mode splitting were observed.

List of Publications – Jonathan Breeze

Refereed Full Papers

1. **Strong coupling between magnons in a chiral magnetic insulator Cu_2OSeO_3 and microwave cavity photons**
   L.V. Abdurakhimov, S. Khan, N.A. Panjwani, J.D. Breeze, S. Seki, Y. Tokura, J.J.L. Morton, H. Kurebayashi, pre-print arXiv:1802.07113, Feb. 2018

2. **Continuous-wave room-temperature diamond maser**
J.D. Breeze, E. Salvadori, J. Sathian, N.McN. Alford, C.W.M. Kay, Nature, 555, 493-496 (2018).

3. **Room-temperature cavity quantum electrodynamics with strongly coupled Dicke states**
J.D. Breeze, E. Salvadori, J. Sathian, N.McN. Alford, C.W.M. Kay, *npj* Quantum Information 3(40), (2017).

4. **Solid-state source of intense yellow light based on a Ce:YAG luminescent concentrator**
J. Sathian, J.D. Breeze, B. Richards, N.McN. Alford, M. Oxborrow, Optics Express 25(12) (2017).

5. **Nanosecond time-resolved characterization of a pentacene-based room-temperature MASER**
E. Salvadori, J. Breeze, K.-J. Tan, J. Sathian, B. Richards, M. Fung, G. Wolfowicz, M. Oxborrow, N. Alford and C. Kay, Scientific Reports, 7 (2017)

6. **Molecular Design of a Room-Temperature Maser**
S. Bogatko, P.D. Haynes, J. Sathian, J. Wade, J.-S. Kim, K.-J. Tan, J. Breeze, E. Salvadori, A. Horsfield, and M. Oxborrow, The Journal of Physical Chemistry C, 120(15), pp. 8251-8260 (2016)

7. **Enhanced magnetic Purcell effect in room-temperature masers**
J. Breeze, K.-J. Tan, B. Richards, J. Sathian, M. Oxborrow and N. McN. Alford, Nature Comms. 6 (2015)

8. **The rectenna device: from theory to practice (a review)**
E. Donchev, J.S. Pang, P.M. Gammon, A. Centeno, F. Xie, P.K. Petrov, J.D. Breeze, M.P. Ryan, D.J. Riley and N.McN. Alford, MRS Energy & Sustainability, 1, pp. E1 (2014)

9. **Room-temperature solid-state maser**
M. Oxborrow, J.D. Breeze and N. McN. Alford, Nature, 488(7411), pp. 353-356 (2012)

10. **Spectroscopic ellipsometry as an optical probe of strain evolution in ferroelectric thin films**
D.Y. Lei, S. Kena-Cohen, B. Zou, P.K. Petrov, Y. Sonnefraud, J. Breeze, S.A. Maier and N.McN. Alford, Optics express, 20(4), pp. 4419-4427 (2012)

11. **Better than Bragg: Optimizing the quality factor of resonators with aperiodic dielectric reflectors**
J. Breeze, M. Oxborrow and N.McN. Alford, Applied Physics Letters, 99(11), pp. 113515 (2011)

12. **Intrinsic microwave dielectric loss of lanthanum aluminate**
T. Shimada, K. Ichikawa, T. Minemura, H. Yamauchi, W. Utsumi, Y. Ishii, J. Breeze and N.McN. Alford, IEEE transactions on ultrasonics, ferroelectrics, and frequency control, 57(10), pp. 2243-2249 (2010)

13. **Temperature and frequency dependence of dielectric loss of $Ba(Mg_{1/3}Ta_{2/3})O_3$ microwave ceramics**
T. Shimada, K. Ichikawa, T. Minemura, T. Kolodiazhnyi, J. Breeze, N.McN. Alford and G. Annino, Journal of the European Ceramic Society, 30(2), pp. 331-334 (2010)

14. **Scattering of light into silicon by spherical and hemispherical silver nanoparticles**
A. Centeno, J. Breeze, B. Ahmed, H. Reehal and N.McN. Alford, Optics letters, 35(1), pp. 76-78 (2010)

15. **Do grain boundaries affect microwave dielectric loss in oxides?**
J.D. Breeze, J.M. Perkins, D.W. McComb and N.McN. Alford, Journal of the American Ceramic Society, 92(3), pp. 671-674 (2009)

16. **Temperature-stable and high Q-factor TiO_2 Bragg reflector resonator**
J. Breeze, J. Krupka, A. Centeno and N.McN. Alford, Applied Physics Letters, 94(8), pp. 2906 (2009)

17. **Enhanced quality factors in aperiodic reflector resonators**
J. Breeze, J. Krupka and N.McN. Alford, Applied Physics Letters, 91(15), pp. 152902 (2007)

18. **Measurements of permittivity, dielectric loss tangent, and resistivity of float-zone silicon at microwave frequencies**
J. Krupka, J. Breeze, A. Centeno, N.McN. Alford, T. Claussen and L. Jensen, IEEE transactions on

microwave theory and techniques, 54(11), pp. 3995-4001 (2006)

19. **Quasi-classical fluctuation-dissipation description of dielectric loss in oxides with implications for quantum information processing**
L.J. Dunne, A.-K. Axelsson, N.McN. Alford, J. Breeze, X. Aupi, E. Bråndas, International journal of quantum chemistry, 106(4), pp. 986-993 (2006)

20. **Characterization and microwave dielectric properties of $M^{2+}Nb_2O_6$ ceramics**
R.C. Pullar, J.D Breeze and N.McN. Alford, Journal of the American Ceramic Society, 88(9), pp. 2466-2471 (2005)

21. **Microwave dielectric loss in oxides: Theory and experiment**
X. Aupi, J. Breeze, N. Ljepojevic, L.J. Dunne, N. Malde, A.-K. Axelsson and N.McN. Alford, Journal of applied physics, 95(5), pp. 2639-2645 (2004)

22. **Ultralow loss polycrystalline alumina**
J.D. Breeze, X. Aupi and N.McN. Alford, Applied physics letters, 81(26), pp. 5021-5023 (2002)

23. **Piezoelectrically tuned dielectric resonators**
N.McN. Alford, P.K. Petrov, J. Breeze and K.S. Sarma, Electronics Letters, 38(16), pp. 855-857 (2002)

24. **Raman Spectroscopic Study of Gallium-Doped $Ba(Zn_{1/3}Ta_{2/3})O_3$**
S.J. Webb, J. Breeze, R.I. Scott, D.S. Cannell, D.M. Iddles and N.McN. Alford, Journal of the American Ceramic Society, 85(7), pp. 1753-1756 (2002)

25. **Dielectric loss of oxide single crystals and polycrystalline analogues from 10 to 320 K**
N.McN. Alford, J. Breeze, X. Wang, S.J. Penn, S. Dalla, S.J. Webb, N. Ljepojevic and X. Aupi, Journal of the European Ceramic Society, 21(15), pp. 2605-2611 (2001)

26. **On the temperature coefficient of resonant frequency in microwave dielectrics**
I.M. Reaney, P. Wise, R. Ubic, J. Breeze, N.McN. Alford, D. Iddles, D. Cannell and T. Price, Philosophical Magazine A, 81(2), pp. 501-510 (2001)

27. **Layered Al_2O_3-TiO_2 composite dielectric resonators**
J. Breeze, S.J. Penn, M. Poole and N.McN. Alford, Electronics Letters, 36(10), pp. 883-884 (2000)

Refereed Conference Publications

1. **Calculations of scattering and absorption efficiencies of noble metal nanoparticles**
A. Centeno, F. Xie, J. Breeze, and N.McN. Alford, IEEE Applied Electromagnetics Conference (2011)

2. **Electromagnetic design of solar collectors**
A. Centeno, F. Xie, J.D. Breeze and N.McN. Alford, PIERS Online, 7(4), pp. 376-379 (2011)

3. **Measurements of permittivity and dielectric loss tangent of high resistivity float zone silicon at microwave frequencies**
J. Krupka, J. Breeze, N.McN. Alford, A.E. Centeno, L. Jensen and T. Claussen, International Conference on Microwaves, Radar & Wireless Communications, pp. 1097-1100 (2006)

4. **Evaluating the properties of dielectric materials for microwave integrated circuits**
A. Centeno, J.D. Breeze, J. Krupka, R.A. Walters, K. Sarma, H. Chien, R.C. Pullar, P.K. Petrov and N.McN. Alford, Challenges in the Modelling and Measurement of Electromagnetic Materials (2006)

5. **Dielectric Loss of Oxide Single Crystals and Polycrystalline Analogues from 10 K to 300 K**
N.McN. Alford, J.D. Breeze and X. Aupi, Key Engineering Materials, 224, pp. 17-22 (2002)

6. **Microwave dielectric properties of columbite-structure niobate ceramics, $M^{2+}Nb_2O_6$**
R.C. Pullar, J.D. Breeze and N.McN. Alford, Key Engineering Materials, 224, pp. 1-4 (2002)

7. **Layered Al_2O_3-TiO_2 composite dielectric resonators with tuneable temperature coefficient for microwave applications**

N.McN. Alford, J. Breeze, S.J. Penn and M. Poole, IEE Proceedings-Science, Measurement and Technology, 147(6), pp. 269-273 (2000)

8. **Temperature compensated high Q and high thermal conductivity dielectrics for Ku and Ka band communications**
N.McN. Alford, J. Breeze, S.J. Penn and M. Poole, IEE Colloquium Digest, 1(117), pp. 6-6 (1999)

9. **The potential use of HTS filters in satellite payloads**
A. Centeno and J. Breeze, IEE Colloquium on Superconducting Microwave Circuits, 1(94), pp.1-1 (1992)

Books

Temperature and Frequency Dependence of Complex Permittivity in Metal Oxide Dielectrics
J. Breeze, Springer Thesis, Springer, ISBN 978-3-319-44545-8 (2016).

Patents Filed

Room Temperature Masing using spin-defect centres
Breeze et al., 2017
Application No. GB P46775GB

Apparatus and method for establishing quantum oscillations
J. Breeze, C. Kay & E. Salvadori, 2017
Application No. GB 1615645.7

Patents Granted

Device and method for generating stimulated emission of microwave or radio frequency radiation
J.D.B. Breeze and N.McN. Alford
US Patent 9293890B2
Granted March 22nd 2016

Temperature stabilization of dielectric resonator
N. McN. Alford, S.J. Penn and J. Breeze
US Patent 6803132B1
Granted October 15th 2004

Electricity generating device
J. Floyd and J. Breeze
World Patent 2002103881A2
Filed June 17th 2002