金刚石色心载入系统研究

The Research of NV loading system

刘光成[1]

School of Physics and Technology
Wuhan University

中国科学院精密测量科学与技术创新研究院, November 2021

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研究计划

金刚石色心粒子载入系统

金刚石色心系统介绍

金刚石 NV[Nitrogen-vacancy] 色心是金刚石晶体中的一种缺陷，由一个取代碳原子的氮原子和相邻一个空位（碳原子缺失）组成。NV 色心有六个电子，两个来自氮原子 $N_7[1s^2 2s^2 2p^2]$，三个来自与空位相邻的碳原子 $C_6[1s^2 2s^2 2p^1]$，另外一个是俘获的电子。

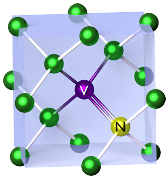


Figure: Nitrogen Vacancy Center Structure
https://en.wikipedia.org/wiki/Nitrogen-vacancy-center

能级结构

3 个 C 原子和 1 个 N 原子提供了四个分子轨道 a_1', a_1, e_x, e_y,NV 系统能级结构可以用 6 个电子占据这四个轨道来解释

特点

- 在室温下即可实现对量子态的制备，操控和读出
- 性质稳定
- 电子自旋可以直接用激光极化和读出
- 可以用微波进行操作

囚禁 NV 的意义

囚禁 NV 之后可以使用激光/微波对其进行一系列操作，并且相比于把 NV 固定起来利用激光操作，悬浮起来的 NV 可以研究更多性质例如 NV 的转动能级耦合等等

金刚石色心粒子载入系统

粒子载入系统

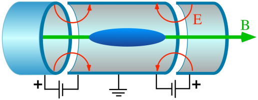


Figure: Penning Trap

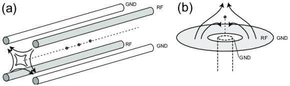
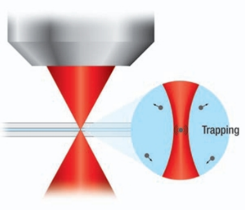


Figure: Paul Trap



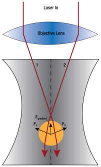
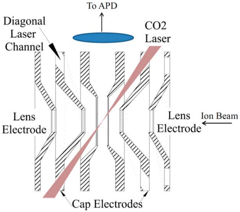


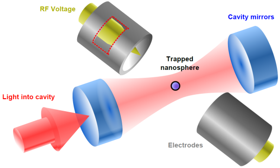
Figure: Optical Trap[1, 2]

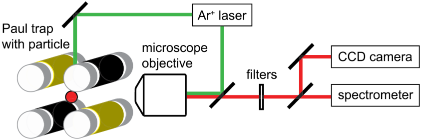
https://en.wikipedia.org/wiki/Penning-trap
https://www.thorlabs.com/

离子阱系统囚禁 NV

离子阱系统囚禁 NV 的优点







各种纳米物体限制在离子阱中已经实现，从柱状纳米晶体[3]、二氧化硅纳米球[4]、含有 NV 中心的微米级金刚石簇[5]

[3]Bell D M, Howder C R, Johnson R C, et al. Single CdSe/ZnS nanocrystals in an ion trap: charge and mass determination and photophysics evolution with changing mass, charge, and temperature[J]. ACS nano, 2014, 8.
[4]Millen J, Fonseca P Z G, Mavrogordatos T, et al. Cavity cooling a single charged levitated nanosphere[J]. Physical review letters, 2015, 114(12): 123602.

使用悬浮在乙醇中的金刚石颗粒的电喷雾电离 [ESI][5],

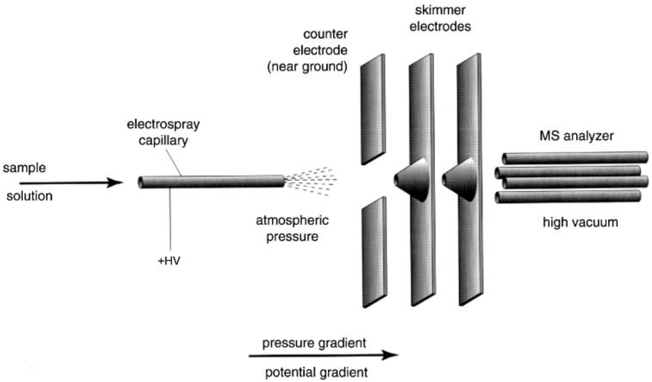


Figure: Essential features of the electrospray interface

Gaskell S J. Electrospray: principles and practice[J]. Journal of mass spectrometry, 1997, 32(7): 677-688.

使用压电转换器[6]

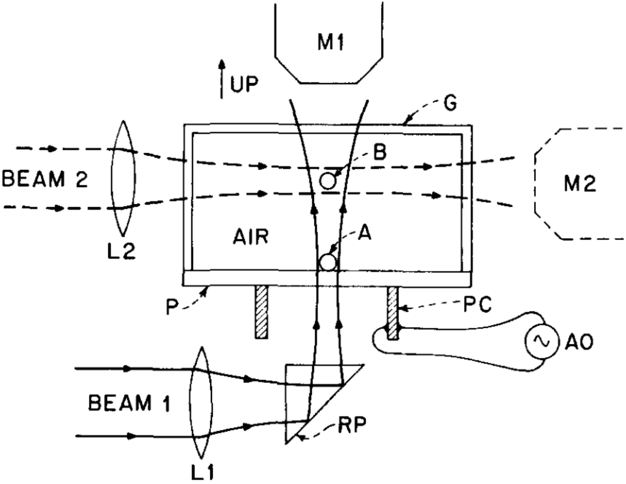


Figure: Levitation apparatus.

Ashkin A, Dziedzic J M. Optical levitation by radiation pressure[J]. Applied Physics Letters, 1971, 19(8): 283-285.

LIAD[激光诱导声学解吸法][6, 7, 8]

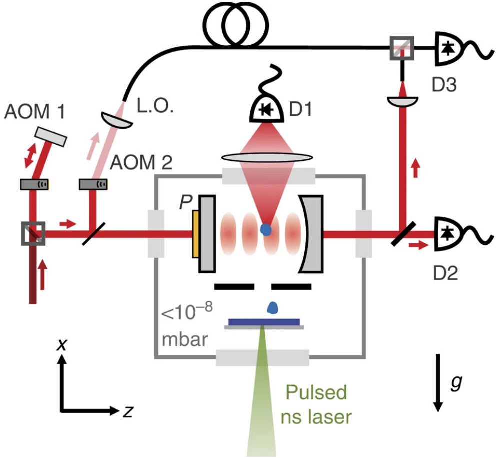


Figure: Laser-induced acoustic desorption

Asenbaum P, Kuhn S, Nimmrichter S, et al. Cavity cooling of free silicon nanoparticles in high vacuum[J]. Nature communications, 2013, 4(1): 1-7.

Dow A R, Wittrig A M, Kenttämaa H I. Laser-induced acoustic desorption mass spectrometry[J]. European Journal of Mass Spectrometry, 2012, 18(2): 77-92.

研究计划

但由于上述载入粒子方法无法准确确定载入粒子数量，每次喷入的粒子利用率不高
所以在离子阱系统中如何准确的载入粒子是需要研究的[9]

1. 构建一个离子阱系统用于囚禁 NV^-;
2. 实现电喷雾电离和 LIAD 方法载入粒子;
3. 进一步改进载入粒子系统使其可以控制载入的粒子，提高粒子利用率;

制备纠缠态

就上面 NV 系统类似, 线性 Paul 阱以及其他的离子阱已经可以长时间的存储粒子，例如线性 Paul 阱是使用的如下势:

$$\Phi(x, y, t) = \frac{x^2 - y^2}{2r_0^2} V_0 cos(\Omega t) \tag{1}$$

多普勒冷却/边带冷却多个粒子

实现量子纠缠态需要两种基本门的操作[10]:

1. 实现旋转 [相位门]

$$\begin{aligned} R_{\Delta n}(\theta, \phi)|g, n\rangle &\longrightarrow \cos\frac{\theta}{2}|g, n\rangle + ie^{i\phi}\sin\frac{\theta}{2}|e, n+\Delta n\rangle \\ R_{\Delta n}(\theta, \phi)|e, n+\Delta n\rangle &\longrightarrow ie^{-i\phi}\sin\frac{\theta}{2}|g, n\rangle + \cos\frac{\theta}{2}|e, n+\Delta n\rangle, \end{aligned} \tag{2}$$

2.CNOT 门

参考文献

[1] https://www.thorlabs.com/.

[2] J. C. Miller, B. D. Brown, T. Shay, E. L. Gautier, V. Jojic, A. Cohain, G. Pandey, M. Leboeuf, K. G. Elpek, J. Helft *et al.*, "Deciphering the transcriptional network of the dendritic cell lineage," *Nature immunology*, vol. 13, no. 9, pp. 888–899, 2012.

[3] D. M. Bell, C. R. Howder, R. C. Johnson, and S. L. Anderson, "Single cdse/zns nanocrystals in an ion trap: charge and mass determination and photophysics evolution with changing mass, charge, and temperature," *ACS nano*, vol. 8, no. 3, pp. 2387–2398, 2014.

[4] J. Millen, P. Fonseca, T. Mavrogordatos, T. Monteiro, and P. Barker, "Cavity cooling a single charged levitated nanosphere," *Physical review letters*, vol. 114, no. 12, p. 123602, 2015.

[5] A. Kuhlicke, A. W. Schell, J. Zoll, and O. Benson, "Nitrogen vacancy center fluorescence from a submicron diamond cluster levitated in a linear quadrupole ion trap," *Applied Physics Letters*, vol. 105, no. 7, p. 073101, 2014.

[6] A. Ashkin and J. Dziedzic, "Optical levitation by radiation pressure," *Applied Physics Letters*, vol. 19, no. 8, pp. 283–285, 1971.

[7] P. Asenbaum, S. Kuhn, S. Nimmrichter, U. Sezer, and M. Arndt, "Cavity cooling of free silicon nanoparticles in high vacuum," *Nature communications*, vol. 4, no. 1, pp. 1–7, 2013.

[8] A. R. Dow, A. M. Wittrig, and H. I. Kenttämaa, "Laser-induced acoustic desorption mass spectrometry," *European Journal of Mass Spectrometry*, vol. 18, no. 2, pp. 77–92, 2012.

[9] D. S. Bykov, P. Mestres, L. Dania, L. Schmöger, and T. E. Northup, "Direct loading of nanoparticles under high vacuum into a paul trap for levitodynamical experiments," *Applied Physics Letters*, vol. 115, no. 3, p. 034101, 2019.

[10] R. Blatt and D. Wineland, "Entangled states of trapped atomic ions," *Nature*, vol. 453, no. 7198, pp. 1008–1015, 2008.