Planar Trap Arrays for Quantum Information Processing and Simulation with two-dimensional Charged-Particle Crystals

M. Vogel[†]

GSI Helmholtzzentrum fuer Schwerionenforschung, 64291 Darmstadt, Germany

Synopsis Individually confined charged particles can be used as qubits, and their mutual interaction in arrays of traps can be taken as a means of simulating quantum systems or processing quantum information. I will introduce to the topic of such trap arrays and give a short account of endeavours in this field of research.

About thirty years ago, quantum information processing with confined ions was proposed by Cirac and Zoller, and scalability was regarded as a central aspect of such systems by DiVincenzo. In the years following that, a number of physical systems and methods have been proposed to realise and demonstrate the preparation of qubits based on confined charged particles such as ions or electrons, and to demonstrate the processing of quantum information via controlled gate operations. As part of this endeavour, the desire arose to work with systems in which each particle is confined separately and by use of static fields only. This has led, amongst others, to the proposition of two-dimensional arrays of planar Penning traps that confine a single ion or electron each, and to use the interaction between the charges as a means of communicating quantum information. Conventional 3D Penning traps can be transformed into 2D versions (see figure 1) that can be arranged in a plane and micro-fabricated on a planar chip.

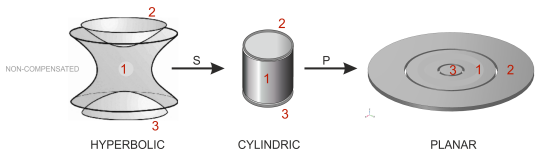

Figure 1. Genealogy of transformations leading to the planar Penning trap (prototypical case).

In the language of plasma physics, the resulting particle arrangements, either of many particles confined in a single trap or of individual particles confined in a multitude of traps, can qualify as charged-particle crystals, either ion Coulomb crystals or electron Wigner crystals in which the degree of particle-particle correlation is so high that only collective descriptions apply, and consequently the rate of communication allows for efficient processing. Similar systems had been proposed even earlier and in parallel also for other applications. A number of experimental endeavours have been undertaken and are currently being pursued, including one at IUAC. I will try to motivate the use of such trap arrays, show principles and examples of experimental realisations and discuss general features from the standpoint of an experimental physicist.

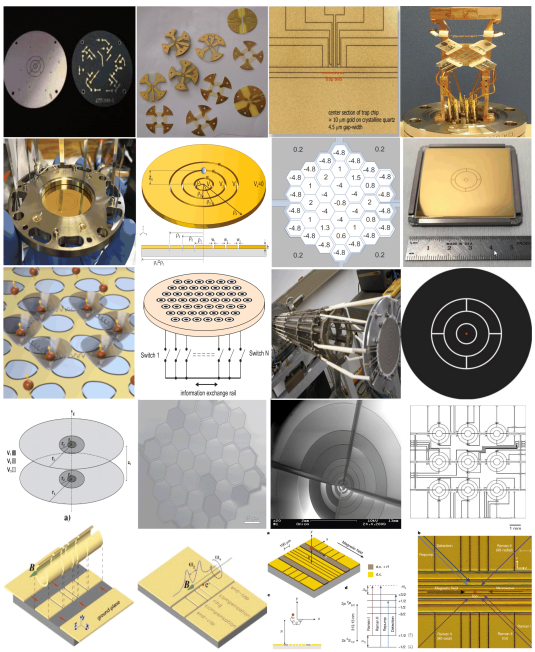

Figure 2. Collage of impressions from the world of planar Penning traps and their arrangement in the two-dimensional plane.

[†]E-mail: m.vogel@gsi.de