Climbing the Photon Ladder; Observation of Fock states In the One-Atom Maser

B.T.H. Varcoe, S. Brattke, and H. Walther
Max Planck Insitute For Quantum Optics and
Sektion Physik, Universität München
Hans Kopfermannstr 1, D-85748, Garching, Germany
Tel +49-89-2891-4032, Fax +49-89-2981-4141
E-mail: B.Varcoe@mpq.mpg.de, Website: http://www.mpq.mpg.de/laserphysics.html

The one-atom maser or micromaser allows one to study the resonant interaction of a single atom with a single mode of a superconducting niobium cavity. In our experiments we achieve values of the quality factor of up to 4×10^{10}, corresponding to an average lifetime of a photon in the cavity of 0.3 s. The cavity is thus considered as a trap for photons. The atoms used in the experiments are rubidium Rydberg atoms pumped by laser excitation into the upper maser level, $63P_{3/2}$, the lower maser level is either the $61D_{5/2}$ or the $61D_{3/2}$ depending on the cavity frequency and the transition frequency is 21.4 GHz. The atom field dynamics is observed by measuring the atoms in the upper or lower maser levels after the cavity. During the interaction the field in the cavity consists only of single or a few photons, nevertheless, it is possible to study the interaction in detail. Thus, the dynamics of the interaction described by the Jaynes-Cummings model can be investigated by changing the velocity i.e. the interaction time of the atoms.

The quantum mechanical treatment of the radiation field uses the number of photons in a particular mode, known as a number state or Fock state, to characterise the quantum states. Fock states therefore represent the most basic quantum states and are maximally distant from what one would call a classical field. Additionally and unlike the classical field, the quantum field has a ground state which is represented by a vacuum state consisting of field fluctuations with no residual energy. Experimentally Fock states are very fragile and very difficult to realise, hence so far they have not been produced experimentally under steady state conditions. To observe a Fock state, the mode considered must have minimal losses and the thermal field, always present at finite temperatures giving rise to photon number fluctuations, has to be eliminated. The first method uses trapping states, allowing the cavity to produce a steady state field[1] and the second method prepares the states dynamically[2]. The latter method has the advantage that the purity of the generated Fock states can be investigated. During the interaction with the cavity the atom and field become entangled [3] and state reduction [4] is used to observe the build up of the cavity field to a known Fock state. We prove the presence of a Fock state using an atom to probe the state of the cavity field producing Rabi oscillations (Fig. 1a). An analytical calculation describing the exact conditions of the experiment was performed[5] showing excellent agreement between experiment and theory (Fig. 1b). The steady state theory is also presented for comparison. Trapping states are formed when the interaction time in Fig. 1 corresponds to the trapping condition $\Omega t_{\text{int}}\sqrt{n+1} = k\pi$, under similar conditions to that of the Fock states and therefore the photon distribution should be equivalent.

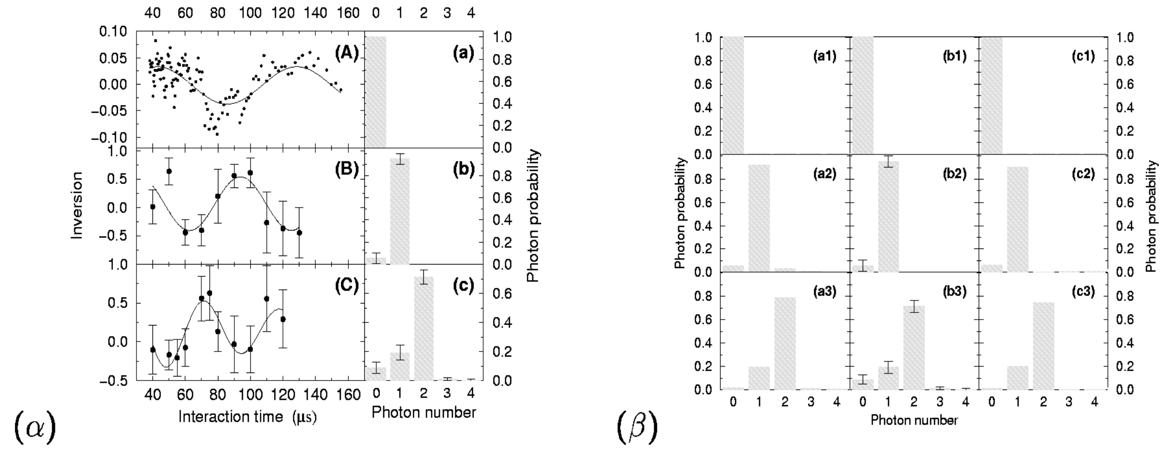

Figure 1: (α) Fock state Rabi oscillations and (β) a comparison between experiment (center) to the analytical model (left) and steady state theory (right) (figures reproduced from [2]).

Fock states have a strong influence on atom-field interactions in the micromaser. Steady state effects such as the recently measured trapping states, which have a strongly peaked single photon number, are one example of this influence. The observed atom-atom correlations and anti-bunching of entangled atoms is also related to the influence of Fock states on the field [3]. Using both the influence of Fock states on the field and the enormous photon lifetimes in our cavity we can engineer non classical atomic beams, while leaving equally non-classical field states in the cavity. Some recent experimental results will be shown.

We also explore an application of trapping states in which they are used to create GHZ states of a combined atom-field system. The preparation of this state requires no special preparation of the atoms, it can be achieved by a manipulation of the interaction time of the atoms between two trapping state conditions.

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