WD1.3 (Invited)
9:30 AM - 10:00 AM

An Optical Ising Machine Based on Multi-core Fiber Lasers

Dan Nguyen*, Veysi Demir, Mehmetcan Akbulut , Pierre-Alexandre Blanche, Mark Neifeld and Nasser Peyghambarian

College of Optical Sciences, University of Arizona, Tucson AZ 85721
**dnguyen@optics.arizona.edu*

Many important problems such as the Graph Partition Problem (GPP) and MAX-CUT problems can be formulated as searching problems of a ground state of an Ising system. Therefore, developing an Ising machine that can find efficiently the ground state of Ising system has been attracted great efforts and activities in recent years. An Ising machine that utilizes the effects of Bose–Einstein condensation and measurement-feedback control has been proposed [1]. However quantum coherence between the different Ising sites is difficult to achieve due to the measurement feedback circuit. An Ising machine that based on a system of coupled slave lasers that are driven coherently by a master laser has been proposed [2]. The modeling results for the VCSEL-based system show Ising states in the system can be reached in about a nanosecond. However, the results also show low output power (small number of photons ~$10^4 - 10^5$) and the complex system that control couplings between master and slave lasers and among slave lasers could be very challenging to realize experimentally. Recently, an Ising machine based on a system of 4 coherently coupled optical parametric oscillators (OPO) has been demonstrated experimentally for the first time [3]. That achievement although is a significant breakthrough in the field, but it can only describe a limit case of Ising Hamiltonian without Zeeman term. Furthermore, the way of generation of cross couplings among the Ising spins (OPOs) would only provide positive coupling coefficients thus prevent it from describing general applications which can have both negative and positive values of the coefficients.

In this work, we propose an optical Ising machine that is based on multi-core fiber lasers (MCFL), which play the role of slave lasers. Specifically, we use a 19-core Yb-doped fiber lasers in the experimental setups. The system is very compact with the length of the multi-core fiber is of about few cm, and the fiber diameter is of 120-micron. In general, the number of cores can be scaled up to a very large number, hundreds or even higher. We propose to use 2 spatial light modulators, SLM1 and SLM2 for polarization control of the couplings from master to slave lasers, and to control the mutual coupling among slave lasers corresponding to Zeeman term, and mutual coupling term, respectively, in Ising Hamiltonian.

$$H = \sum_{i<j} J_{ij}\sigma_i\sigma_j + \sum_i \lambda_i\sigma_i \qquad (1)$$

In Hamiltonian (1) σ_i describes an Ising spin, J_{ij} is a mutual interaction (coupling) between spin i and spin j , and λ_i is a supplemental Zeeman (external magnetic field) term.

Fig. 1 shows a simplified schematics of our Ising machine with key components: the MCFL in this case is 19-core Yb-doped fiber with cross section shown; the mutual interaction is ensured by a diffractive element that couples the light from any one core back into all the cores. The state of the master oscillator can be selected independently for each core thanks to an active polarizing element such as an LCoS SLM.

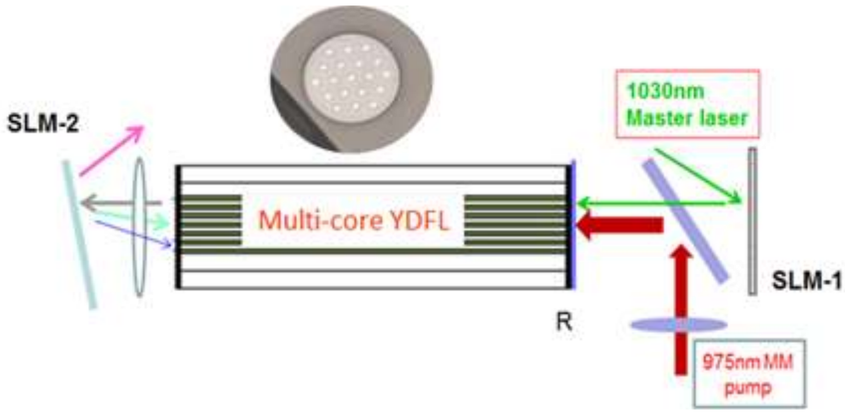

Fig. 1 Simplified schematics of Ising machine based on multicore fiber lasers

In Fig. 2, the average photon numbers in two polarization states are equal $n_{Ri} = n_{Li}$ at t=0 due to the initialization induced by the vertically polarized injection-locking signal from the master laser.

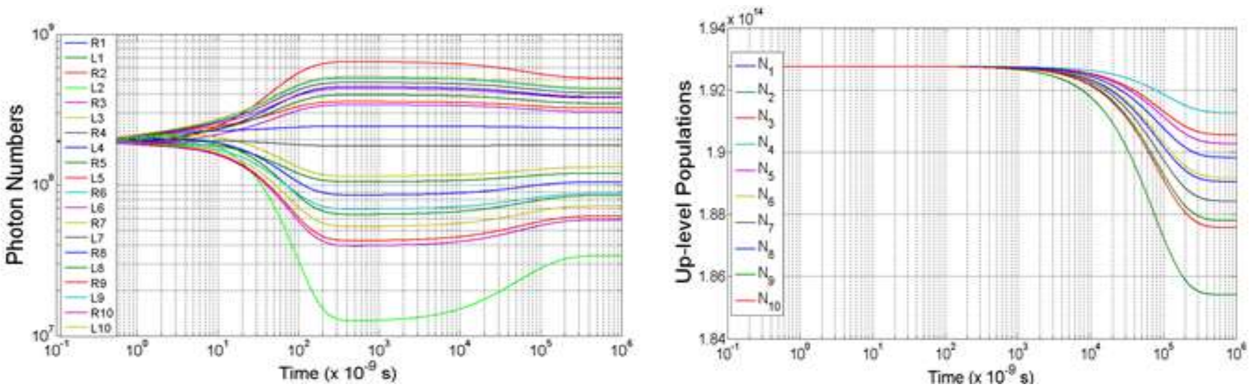

Fig. 2 Time evolution in system of 10 slave lasers. Left: verage photon numbers with right- and left-polarized states n_{Ri} and n_{Li}, Right: average up-level population in Yb-doped fiber cores

After a time delay of less than 1 *ms* the average photon numbers in two polarization modes depart from each other due to the effect of polarization control from master (Zeeman term) and the mutual couplings among the slave lasers. The system reaches a steady state with a delay time of about 1*ms*. That is how the proposed Ising machine spontaneously select the specific polarization configuration which minimizes the overall loss and achieve the minimum gain principle for the whole system, therefore the ground state of the Ising Hamiltonian can be found efficiently using this system.

Authors acknowledge the support of the Office of Naval Research under grant #N00014-14-1-0505, and supports from CIAN

References

1. T. Byrnes et al., "*Optimization using Bose-Einstein condensation and measurement-feedback circuits*", arXiv:0909.2530v2 (2009)
2. S. Utsunomiya et al., "*Mapping of Ising models onto injection-locked laser system*", Optics Express, Vol 19, 18091 (2011)
3. A. Marandi et al., "*Network of time-multiplexed optical parametric oscillators as a coherent Ising machine*", Photonics Nature, Vol 8, 937 (2014)