A survey of the development of x-ray laser research

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Almost contemporaneously with the building of the first optical laser at wavelength 694 nm in 1960, theoretical speculation and experiments were underway to produce lasing at shorter wavelengths in the x-ray range. Focusing optical lasers into non-linear media produces useful harmonic output at short wavelengths, but efficiencies are typically small ($\sim 10^{-6}$) and the harmonic process requires typically < 100 fs laser pulses so the short wavelength output power is limited. Due to the high energy density required to pump a transition with high photon energy, studies aimed at achieving high power output involved the production of high temperature plasma. Successful mechanisms to produce short wavelength lasing at first centered on a recombination approach, where a hot plasma formed in a picosecond duration optical laser-plasma is rapidly cooled leading to preferential population of higher level quantum states and population inversion. In the 1980s, a new approach involving collisional excitation of closed-shell ionic configurations (neon-like and nickel-like ions) achieved high output saturated lasing where stimulated emission significantly depletes the upper quantum state. In the 1990s to 2000s, much experimental effort extended the range of plasmas where these collisionally-pumped lasers operated. In laser-plasmas, a pre-pulse and grazing-incidence input of the main pumping pulse was found to increase the absorption and to deposit the pumping laser energy at the optimum density. This allowed lasing at short wavelengths with pumping from high rep rate optical lasers of duration several picoseconds with energy less than one joule per pulse: conditions enabling table-top short wavelength laser action. Capillary lasers were also developed where a sequence of electrical discharges through argon contained in a narrow ceramic capillary produces the necessary plasma energy density to produce lasing in neon-like argon. Plasma-based x-ray laser work increased understanding in the atomic physics of plasmas, trained many people and shaped the development programs of x-ray free electron lasers. X-ray free electron lasers first demonstrated in 2010 exploit the high energy density of electrons accelerated to relativistic energies in the type of devices previously used for particle physics experiments. A ponderomotive force (due to the high laser radiation energy density) causes electrons to microbunch so that an undulator (a periodic spatially oscillating magnetic field) accelerates electrons to produce coherent high power x-ray output proportional to the square of the number of magnetic oscillations and the square of the number of electrons in the microbunch.