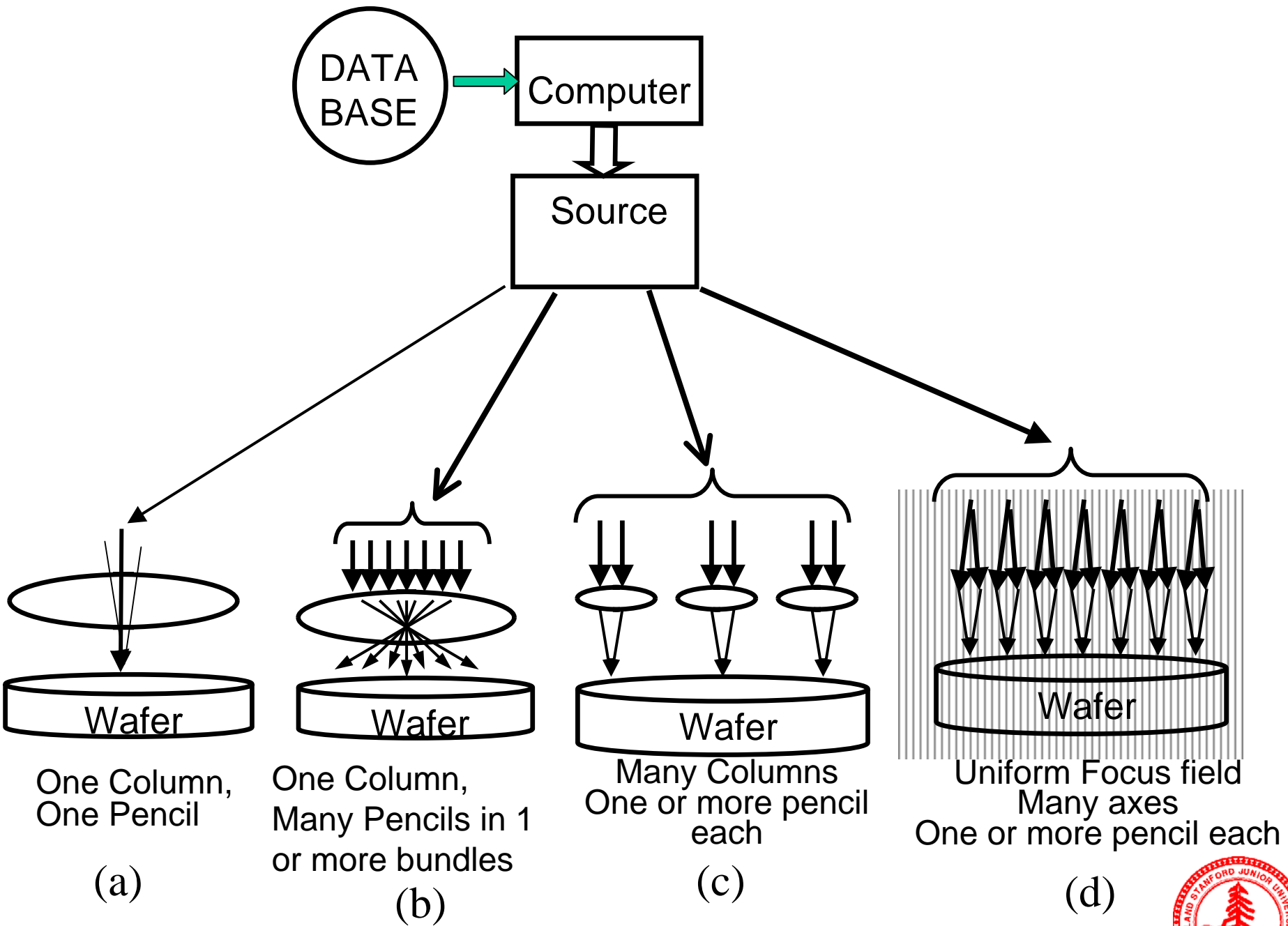


Charged Particle Maskless Lithography (CPML2)

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Four Limitations to Throughput W

- **Dose required by the resist**; not a serious problem for OML.

For CPML2. $W \leq I/Q$; to maintain $W=1\text{cm}^2/\text{s}$ for $Q=1\mu\text{C}/\text{cm}^2$ we need $I \geq 1\mu\text{A}$. This might just be practical for an MFS of 200nm in a single-bundle system but not for 25nm. Hence a multi-bundle system seems to be needed.

- **Scan speed**. E.g. a CPML2 system with a stage speed of $v\text{ cm/s}$ and sweep width $y\text{ cm}$ has $W \leq vy\text{ cm}^2/\text{s}$; for a n -bundles $W \leq nvy\text{ cm}^2/\text{s}$. Mechanical stage speed does not seem to be a serious limiting factor for CPML2 especially as on grounds of required total current multiple bundles are needed.

For OML the source (PRF) of 10KHz and the difficulty of high-speed scanning may lead to the need for about $1e8$ pencils; probably the biggest challenge for OML.

- **Frequency f of modulation** =100THz for the naïve system where the beam only exposes one MAU at a time. So we should aim for a system that exposes at least 10^5 MAU's simultaneously.

- **Shot noise** appears to be the most serious limit for CPML2 and for EUV as feature sizes shrink below 50nm . The required dose may increase by $(\text{MFS})^{-4}$.



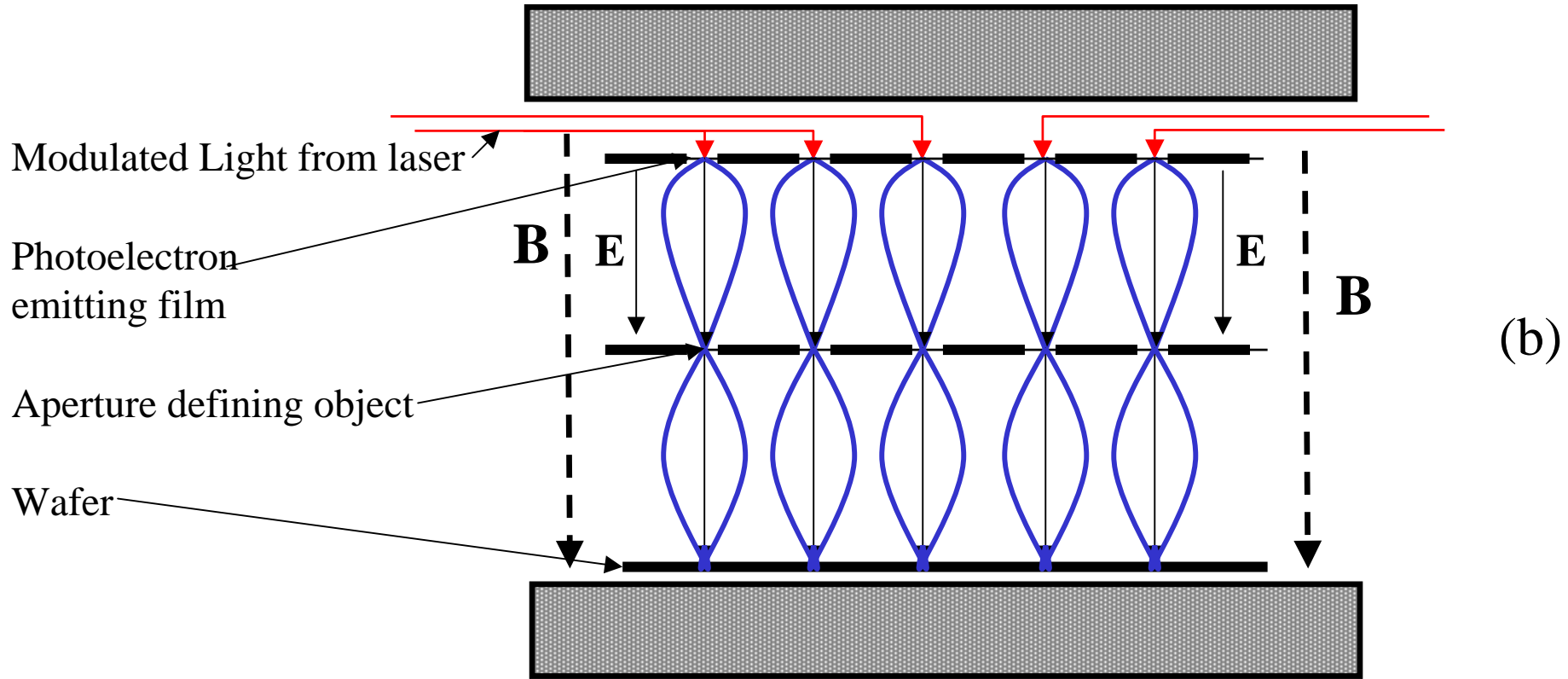
Fundamental Shot Noise Limits

- Designers require one MAU = MFS/50 (Oldham); so each MF must receive sufficient quanta to maintain control of edge position to 1 MAU .
- We do not know how many of quanta per MAU or per MFS we need to achieve this control.
- 1 quanta per MAU is too small and 100 probably too safe; pick 10. this translates to 25,000 per MFS to satisfy today's designers.
- For a MFS of 50nm (1MAU=1nm) the required dose is 10quanta/nm² (for 25nm, 100).
- One quanta from an ArF laser has about 5eV; so 10 quanta/nm² comes to about 10J/m² or 1mJ/cm² so is not a significant limit.
- For EUV quanta we need about 20mJ/cm² ; this is serious as current projections for the throughput of EUV are based on 5mJ/cm².
- Singly-charged particles need at least 160μC/cm² or about the chemically required dose of PMMA to 25keV electrons. For a MFS of 25 nm we will need about 640 μC/cm² or about the dose required by HSQ.
- These minimum required doses are independent of the chemistry of the resist or the species or energy of charged particle.

So we need nearly 1mA, about 100x current of tomorrow's EPL tools



2nd example: Distributed Axis configuration of Groves, Pickard et al.
The focusing of the aperture objects onto the wafer is entirely due to the uniform magnetic field



Better than 50nm resolution has been obtained as a proof of concept.
(Pickard et al. JVSTB Nov/Dec 2003)



The key to success in this, as in so many other lithographic systems, is the source. Hence almost all the EBL effort at Stanford is concentrating on this with support from DARPA, SRC, DoE (SSRL), AMAT and KLA Tencor.

Projects include:

- GaN-based photocathodes (Machuca, Liu, Pianetta)
- CsBr-based photocathodes (Maldonado, Pianetta)
- Plasmon-based photocathodes (Pickard),
- Electron-bombarded semiconductor cathodes (Pickard).

Preliminary results with a combination of AlGaN and CsBr are encouraging e.g. $J > 10 \text{ A/cm}^2$, $\Delta-E < 0.4 \text{ eV}$, Lifetimes > 3 hours (Machuca, Maldonado and Liu Private communication)



- CPML2 is already being used in very low volume ($0.001\text{cm}^2/\text{s}$) production
- Throughput must be $1\text{cm}^2/\text{s}$ and feature size 50nm initially, extending to 25nm .
- For presently available CP (and EUV) systems the main challenge appears to be achieving the required current and resolution because of shot noise. For a given electron-optical configuration the throughput decreases as the fourth power of minimum feature size (below 50nm).
- 25nm features at $1\text{cm}^2/\text{s}$ might be achieved using a multi-axis electron beam system; the author can see no other way of accomplishing this goal.
- Such a system could also be used for greatly accelerated (at least $100\times$) SEM inspection.
- The lack of a suitable source is still the primary technical obstacle.

