On-chip Inductors and Transformer

Applied Power Electronics Conference
SP1.4 Power Supply on a Chip - PwrSoC

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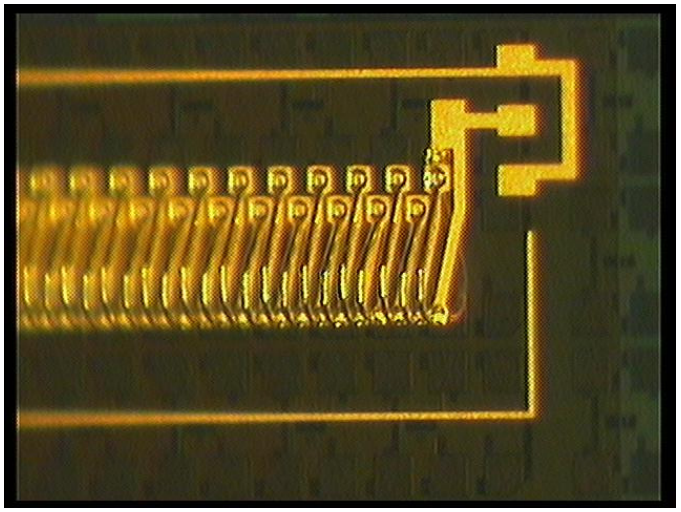
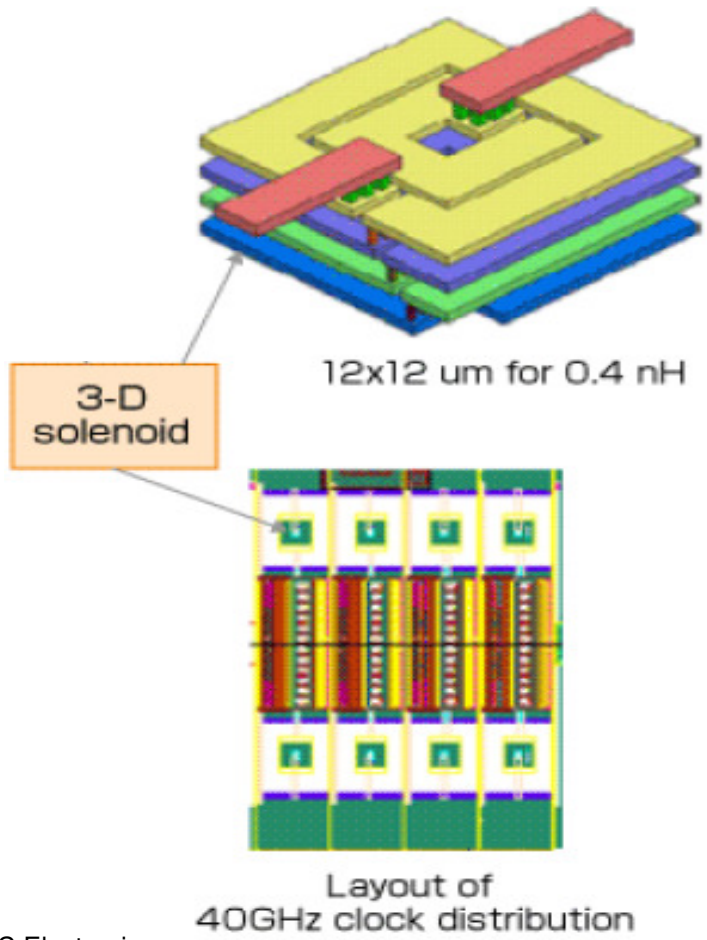
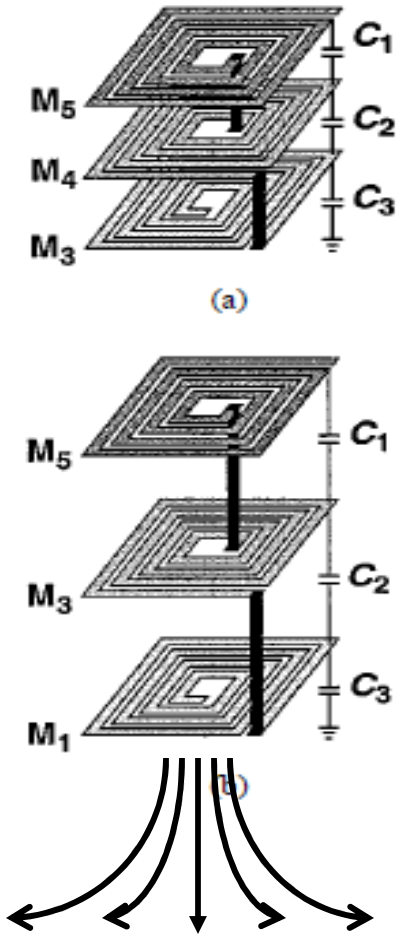


RFIC's Planar Spirals



NEC Electronics



< 10 nH

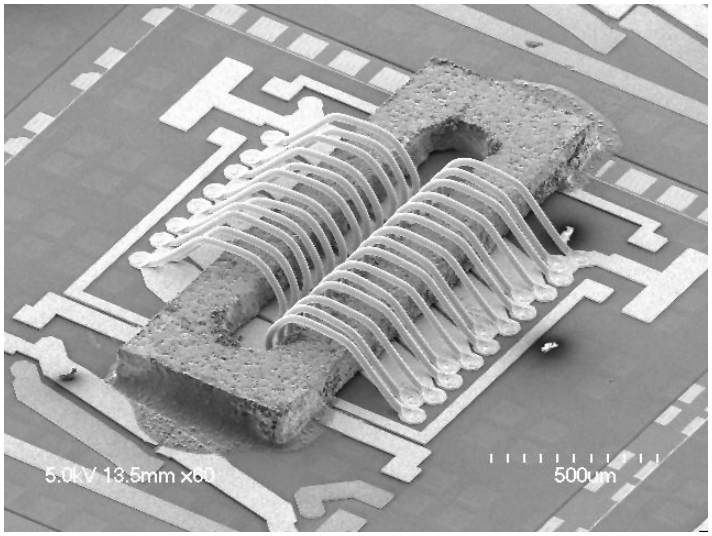
Eddy currents

Not over actives

EMI

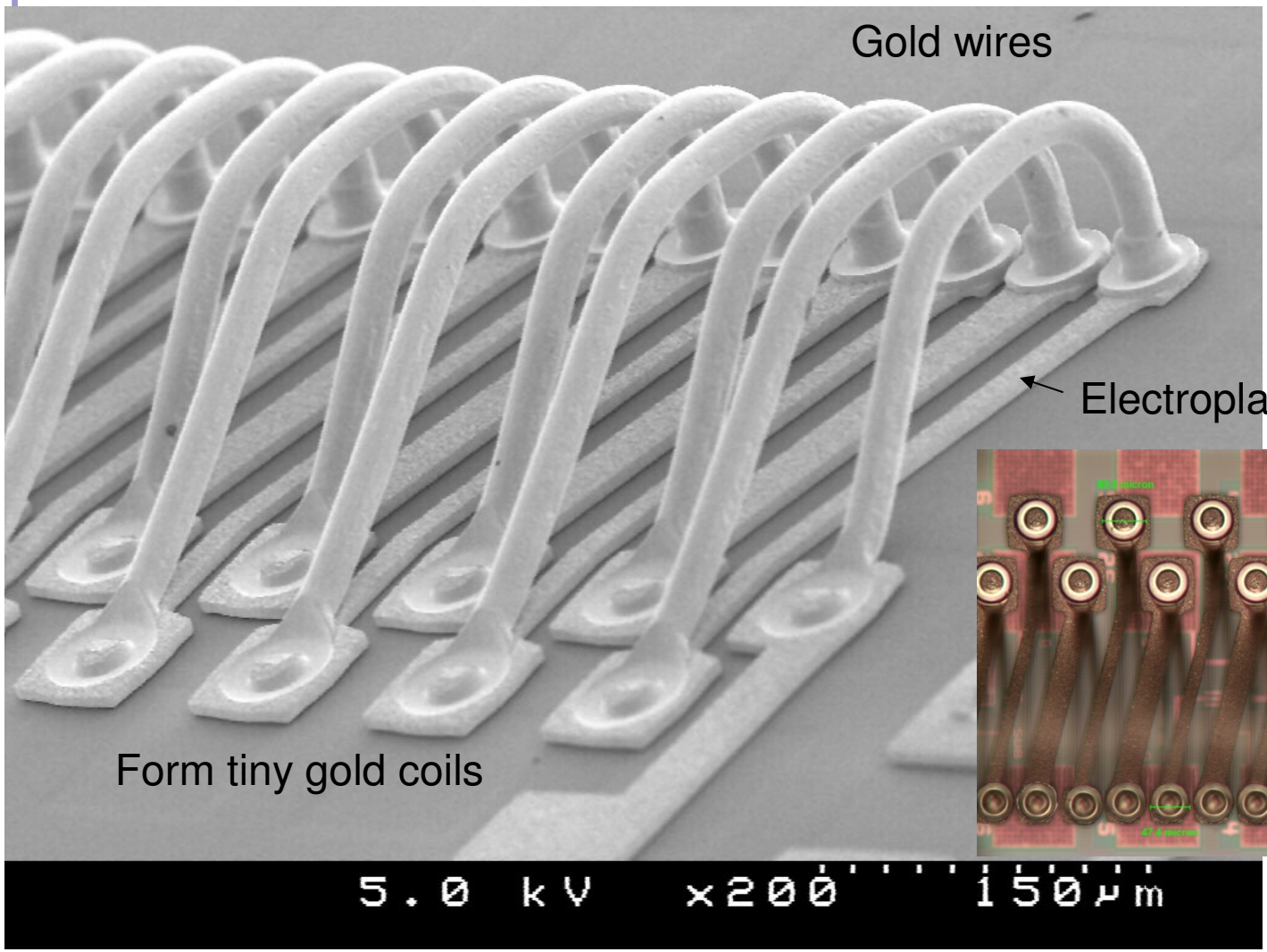
On-chip Inductors

- 5nH to 2700nH
- Low Rdc, 9 μm thick gold
  RF skin effect
- Magnetic cores >100 μm thick
  Optimize to frequencies
- Low cost production processes



- Flexible design, trim-able
- Minimize EMI directly over active IC circuits
- Small; multiple inductors onto existing chips

Linear Gold Inductor

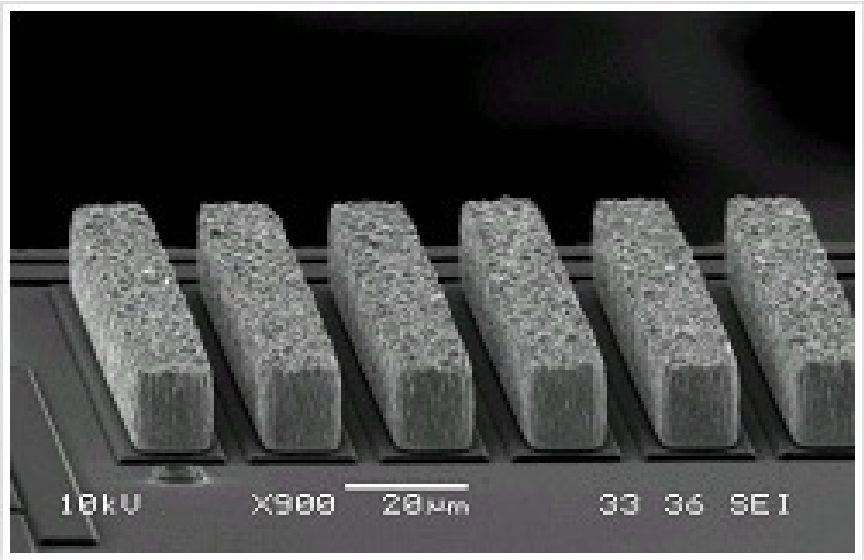


< 250 µm
loop height
54 µm
wire pitch

Gold Over Passivation Metals

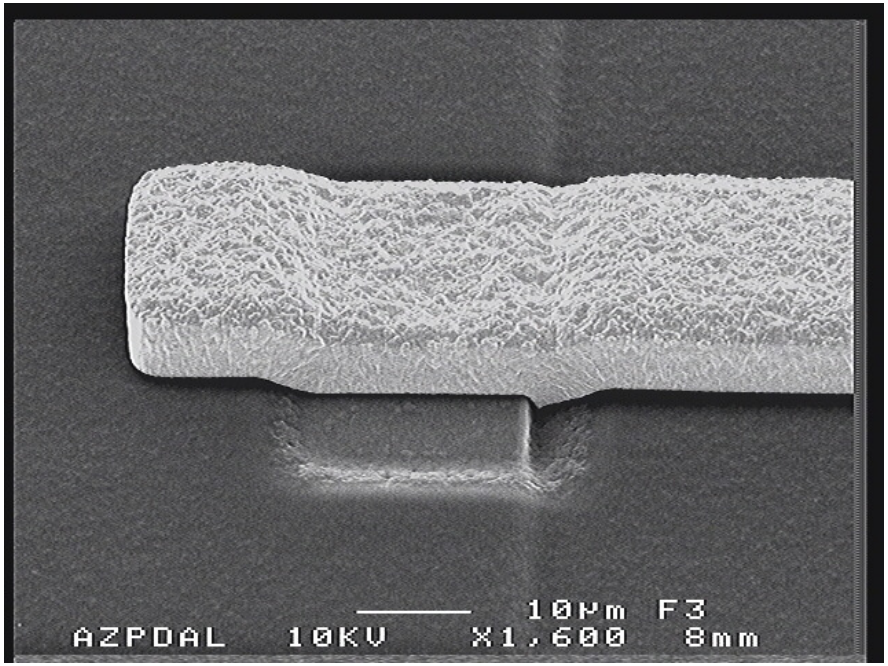
Power Gold

18 µm thick gold bumps



TAB for LCD Driver ICs

9 µm thick Power Gold



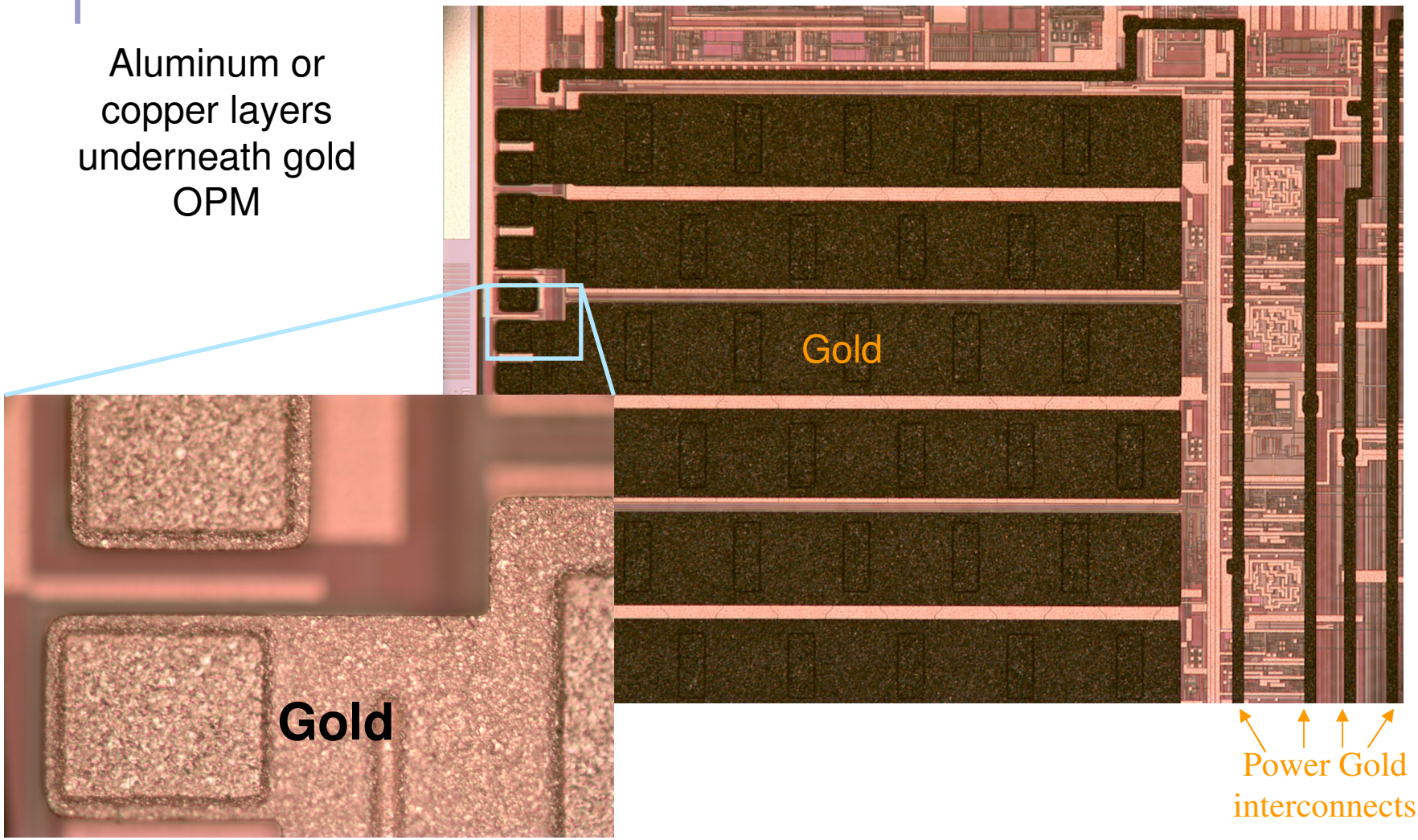
Wire bond pad & interconnect line
for microcontrollers

Publication:
"Power Gold for 175C Tj-max", J. Wang and B. Baird at Pan Pacific Microelectronics Symposium, Feb. 2003, pp241

Gold on IC

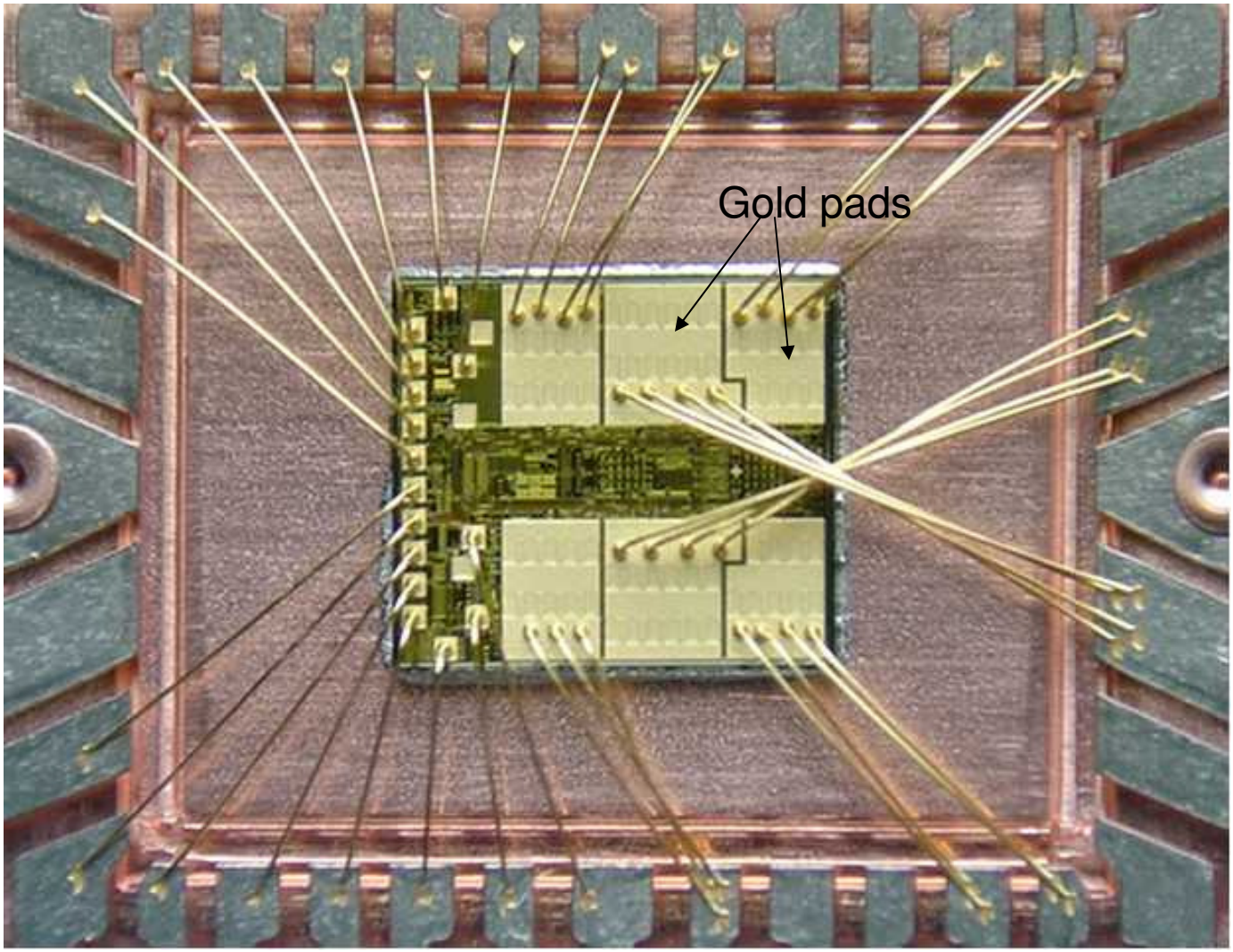
Power Gold

Aluminum or copper layers underneath gold OPM



Wire Bonds onto Gold Pads

Power Gold

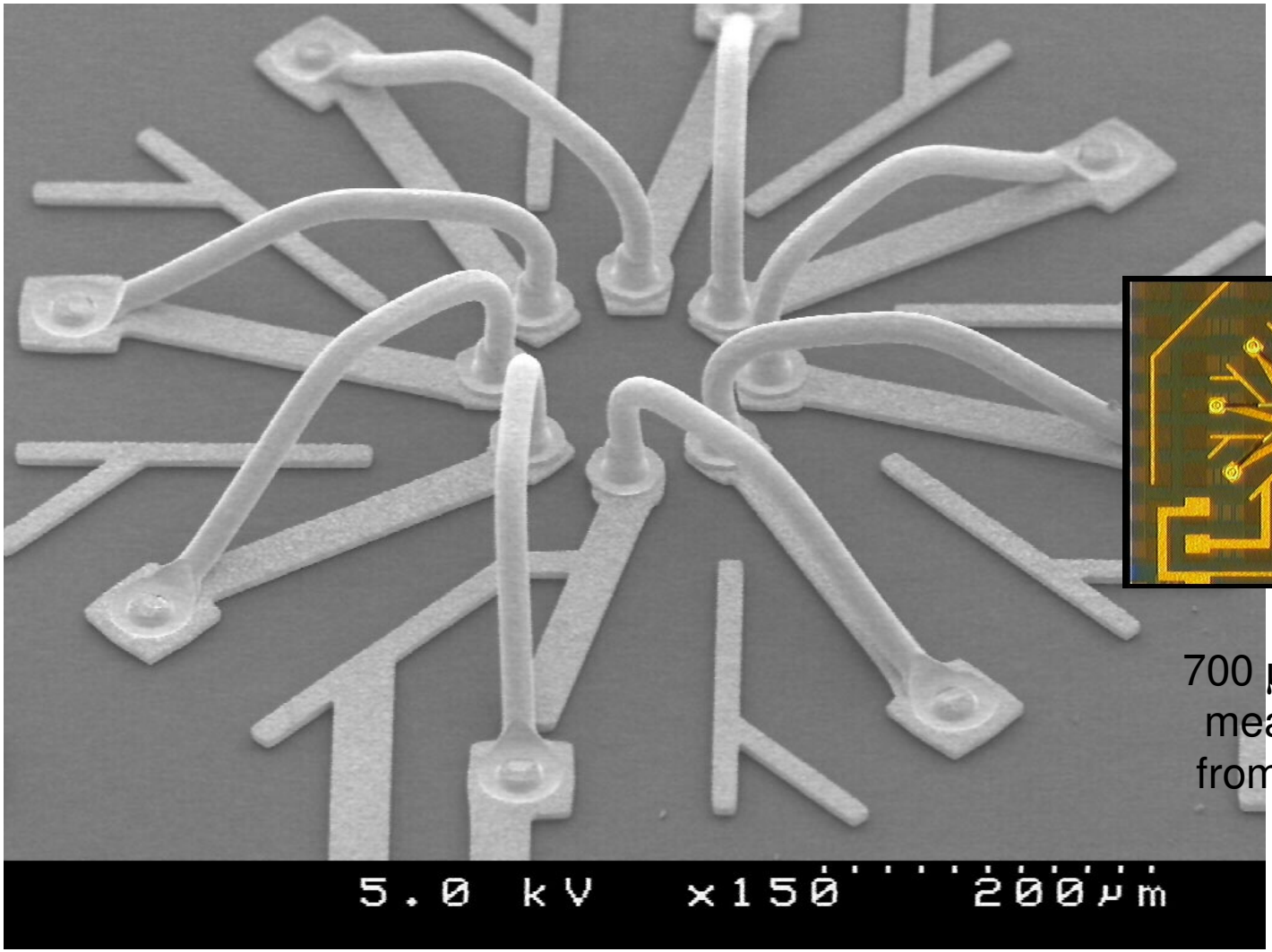


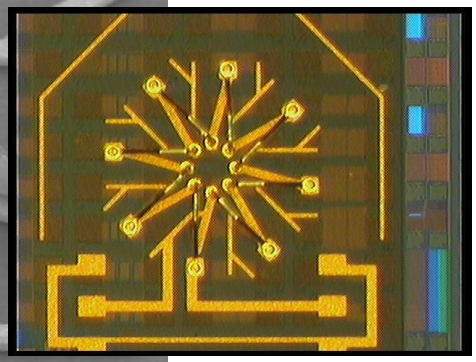
Wire bonds over actives

Stronger gold-bold bonds

3x more gold in 2 mils wires than electroplated gold on-chip

Toroidal Gold Inductor





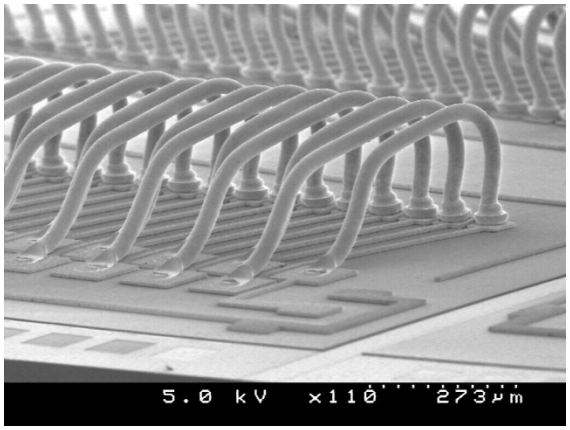
700 µm diameter;
measures 8 nH
from 1-300 MHz
Q = 7

Advantages of Gold Inductors™

- Tiny: < 1 mm diameter x 0.25 mm height
  Fits 1 mm thin QFN packages

- Integrate 2, 4, 16 or more on-chip inductors
  Add onto existing ICs

- Gold ball bonds + electroplated thick gold
  Production ready, low cost
  Volume processes & tools



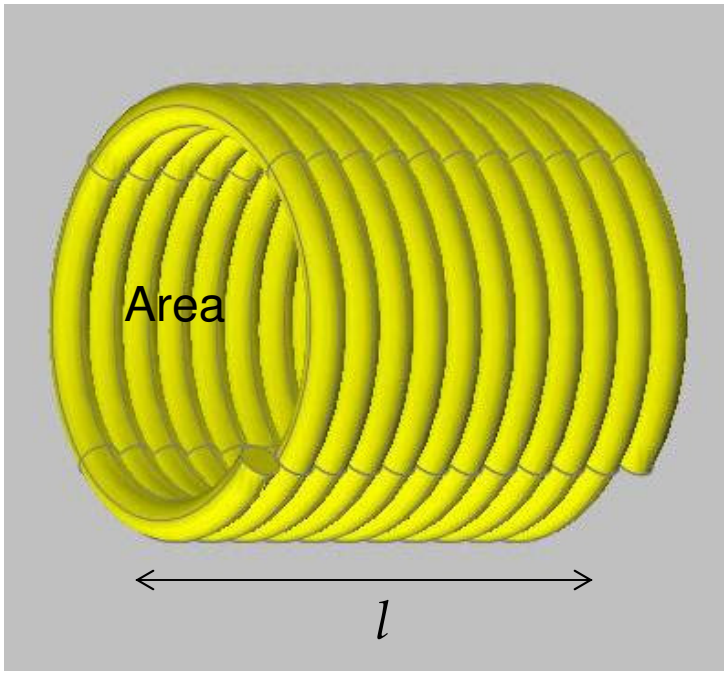
- Lower cost than discretes (0402 chip-inductors)

- Alter inductance by adjusting wire loop height

- Gold is ideal > GHz, RF frequencies

Inductor Physics

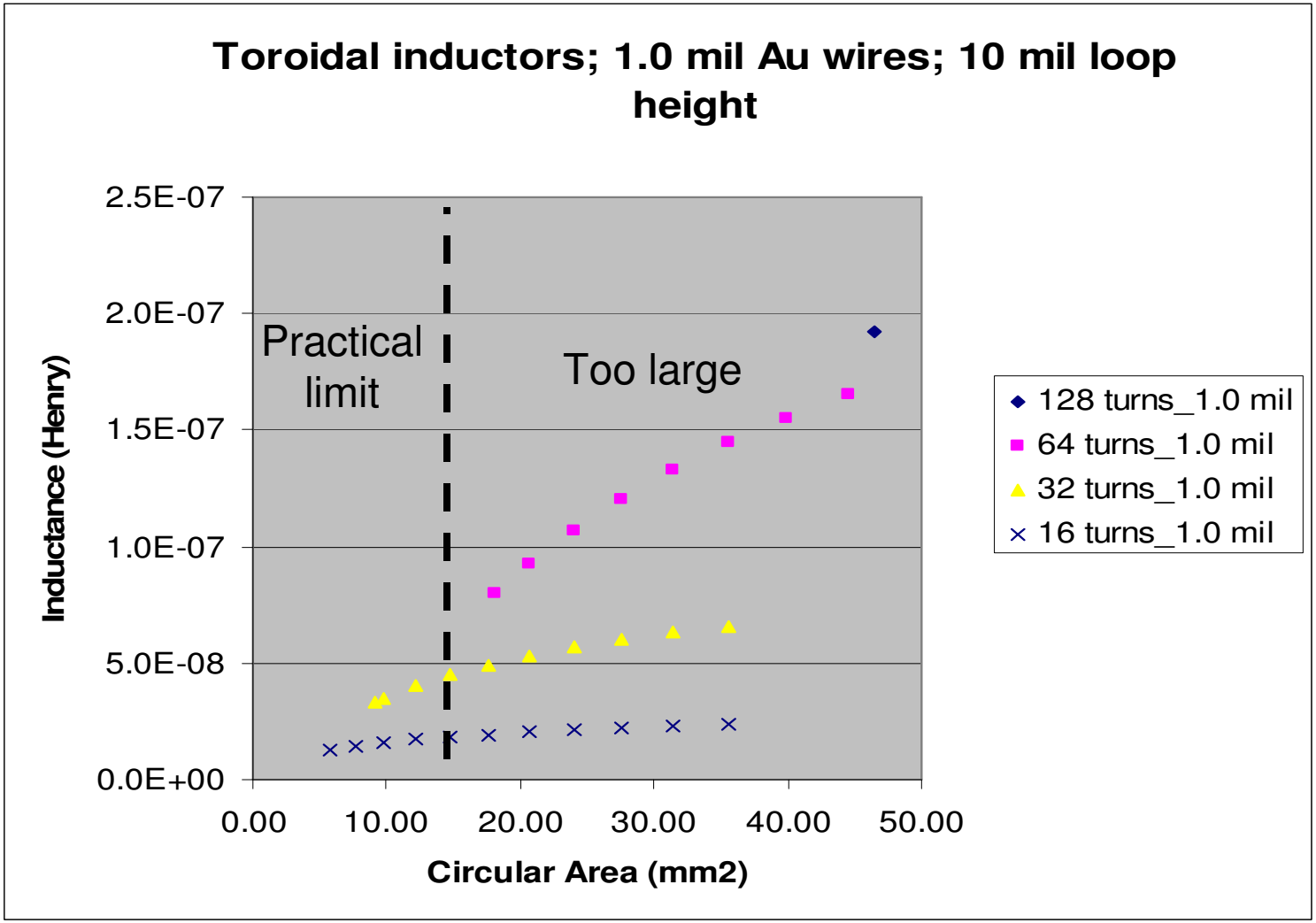
$$L = \mu_0 n^2 l A$$



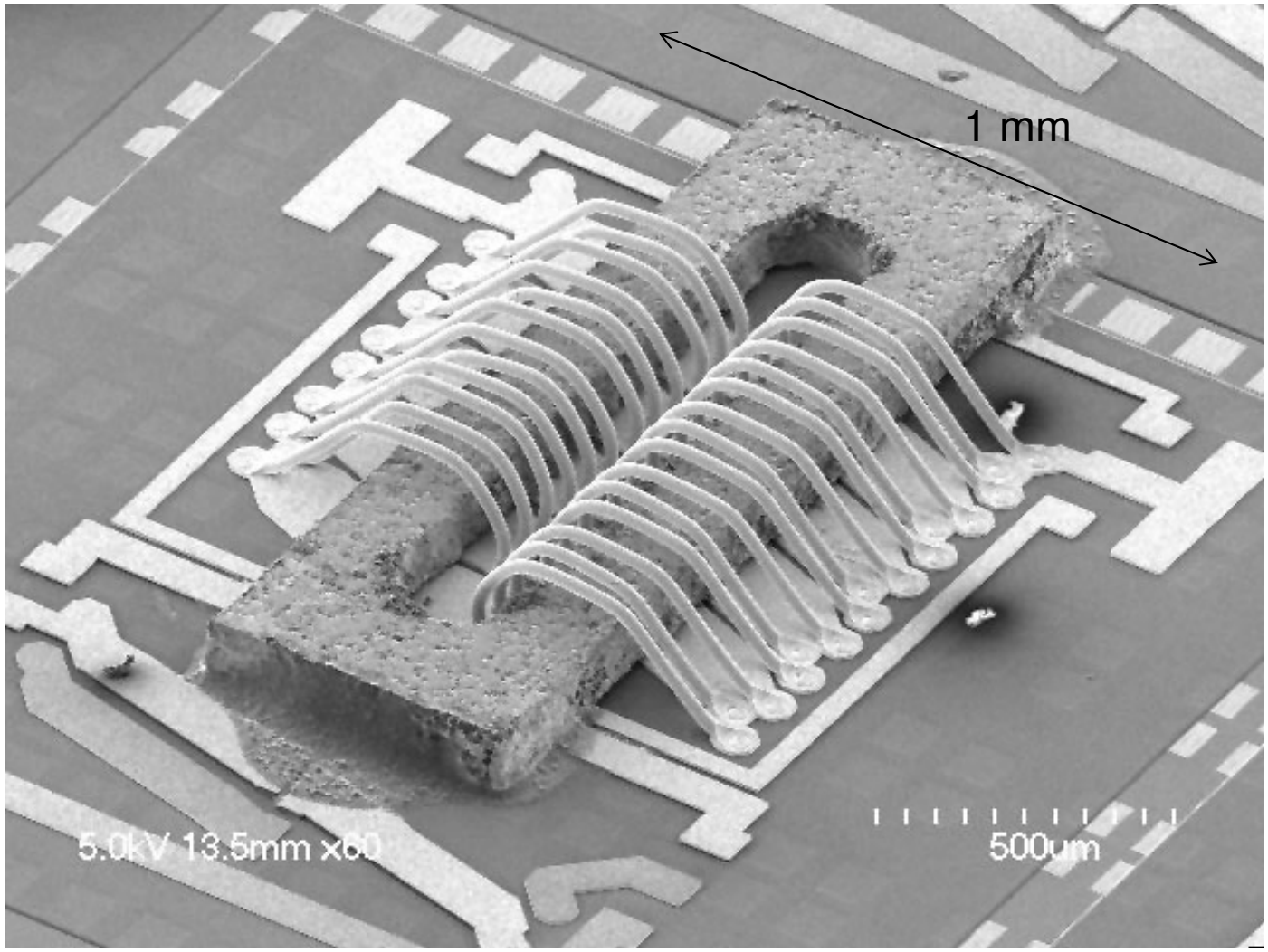
L = inductance value

μ_0 – $4\pi \times 10^{-10}$ Henry/mm
n – number of turns/unit length
l – length of inductor coils
A – cross-sectional area of linear inductor

Larger Air Core Toroids



Ferrite Core Gold Inductor

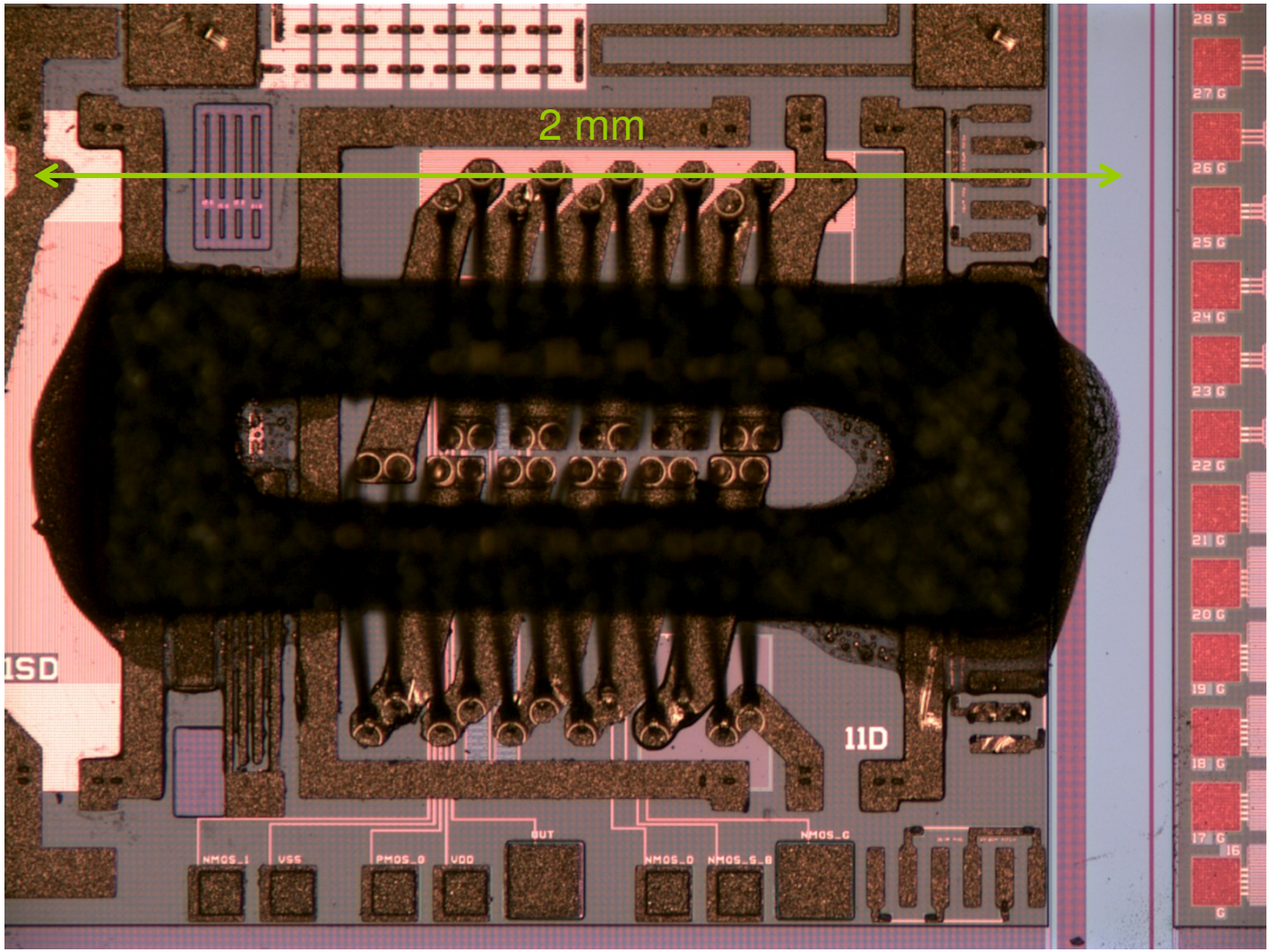


9 Turns
1x2x0.2
mm

150 nH

Q = 6
@ 2.4 MHz

11 Turns Gold Inductor

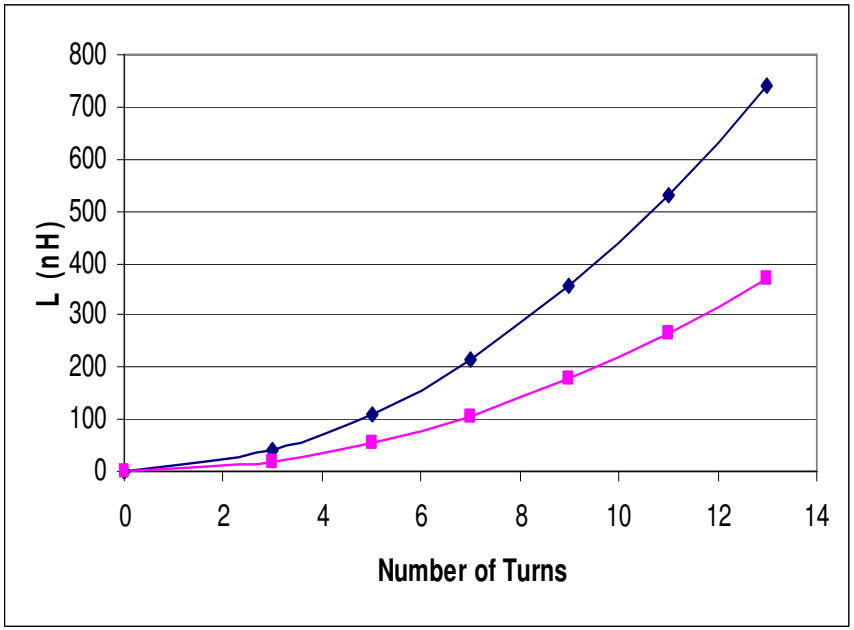


Ring oscillator, transistors test structures underneath inductor to evaluate interference.

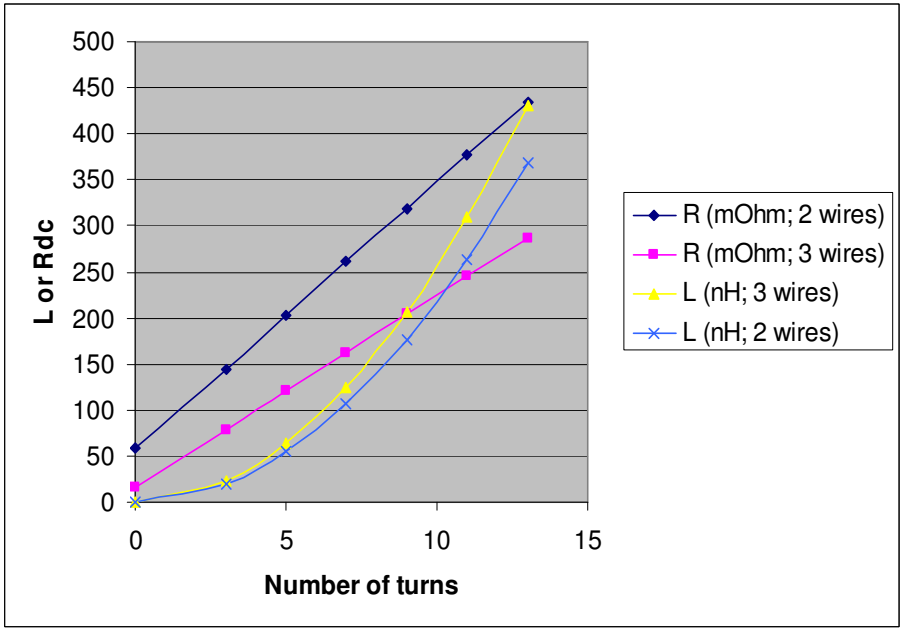
Rdc & Inductances

Ferrite Cores measured @ 5 MHz

2 ferrite materials

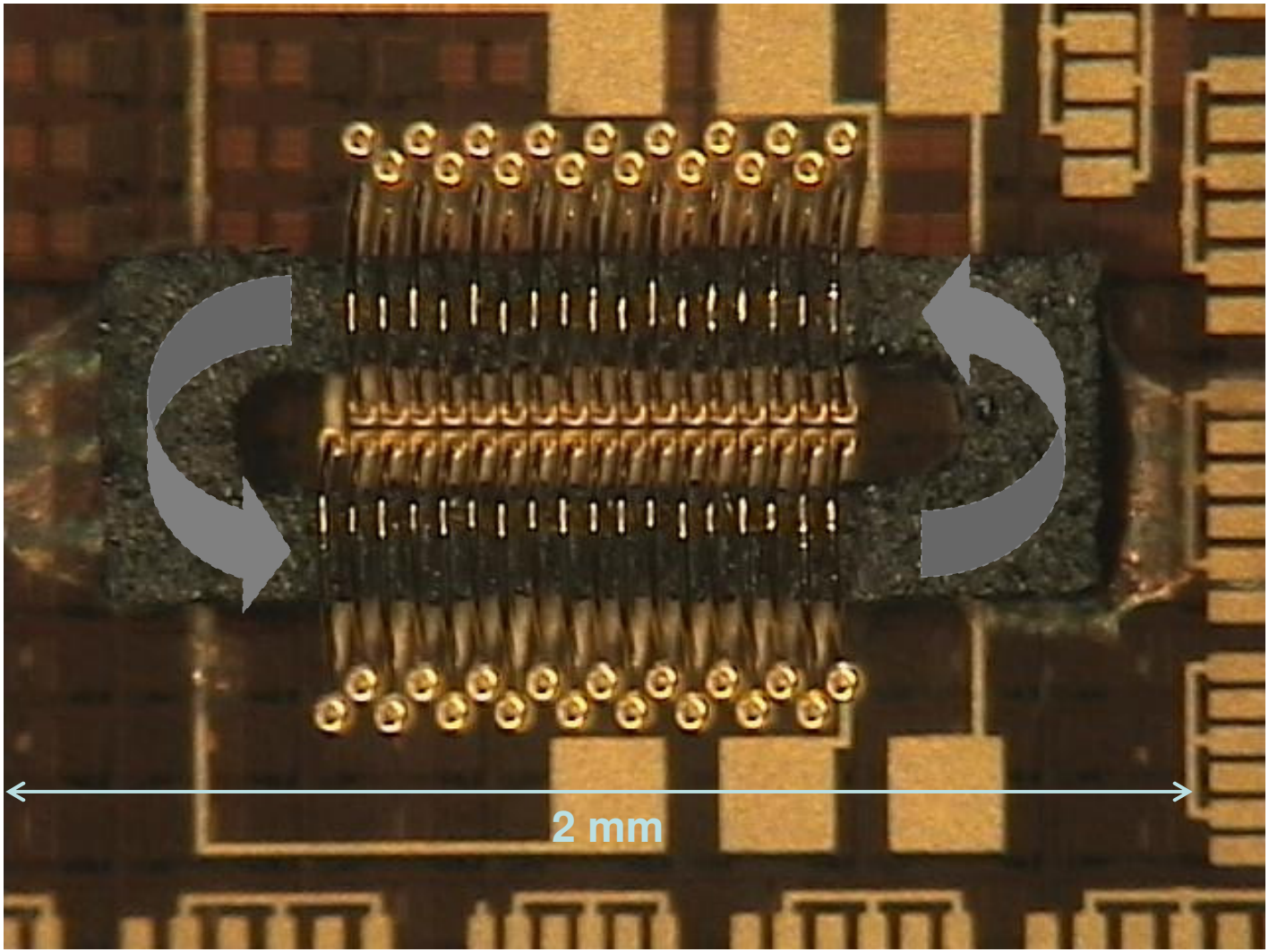


Parallel wires



Measurements: Marilyn Stuckey & Hanyu Sheng

Magnetic Field Lines

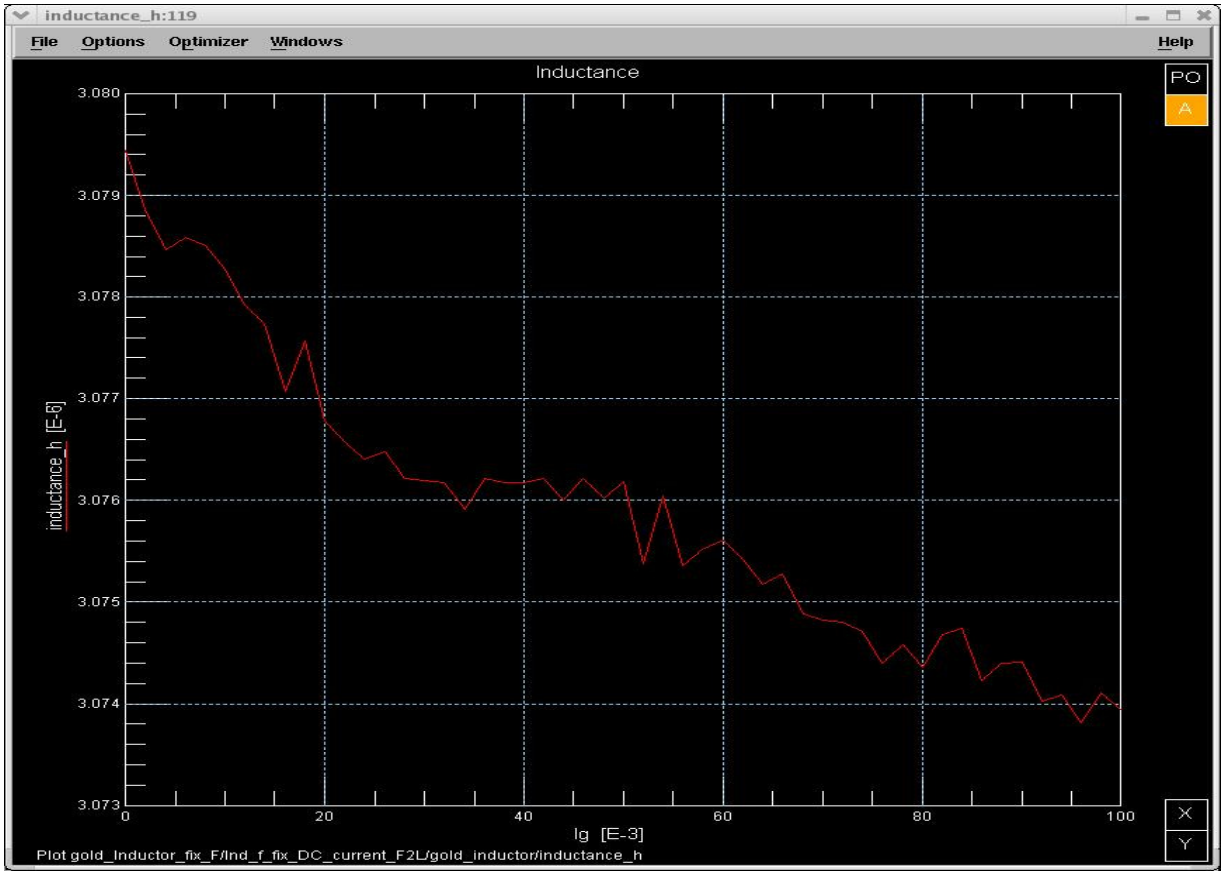


Ferrite core

35 turns coil designed to keep the EM field lines within the core, parallel to IC surface

>1500 nH

Isat > 1A

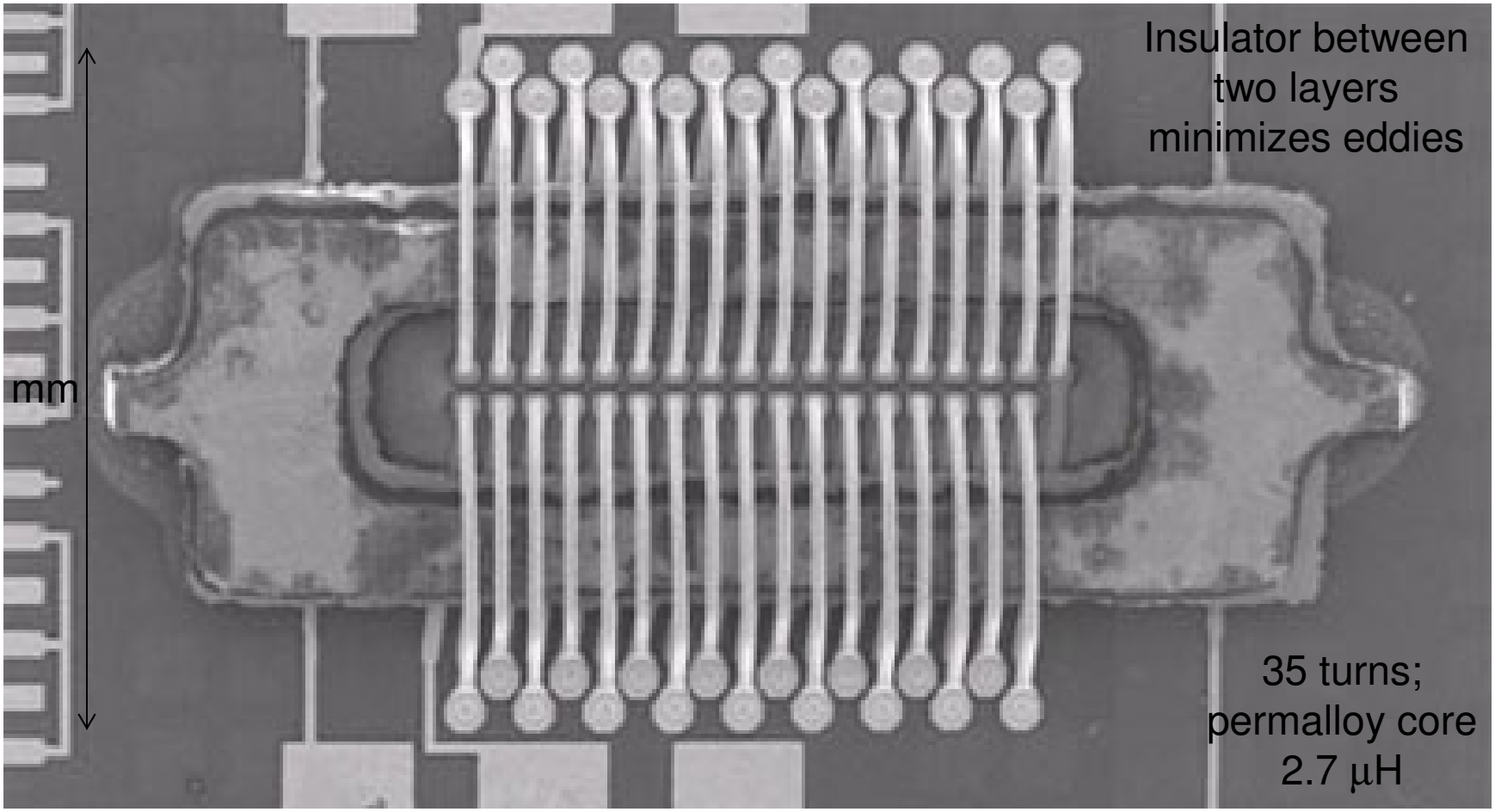


Measured L @ 5MHz decreased less than 1%; tested to 1 A

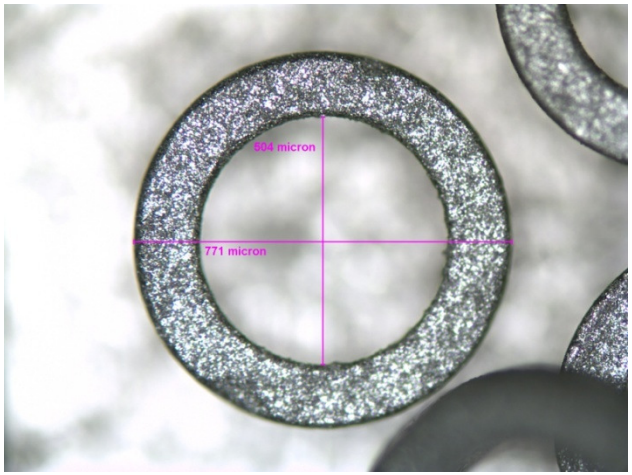
Ferrite core

Designing Transformer

primary/secondary coils



Material Possibilities



Inductor cores:

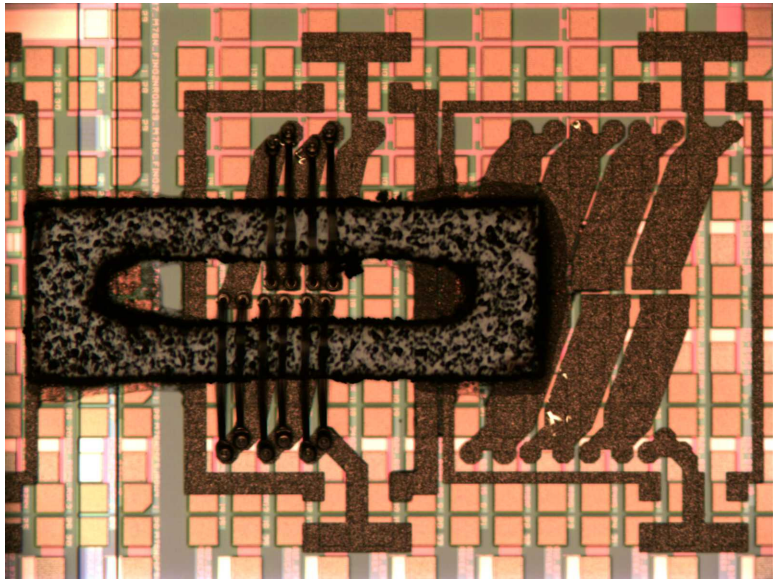
- Air (lowest cost)
- Ferrites (130 μm thick)
- High permeability permalloy (105 μm thick)
- Glob-top with magnetic filler particles
- Other materials not yet tried
- Round, rectangular, octagonal, etc.

Custom for frequency, L, Q

Ready for IC Evaluations

Power Gold

- Layout inductors over existing ICs
  - Design & processes available
  - Prototype then evaluate
  - Characterize & optimize
- ESD, spike current protection
- Shrink hand-held devices
- Lowers cost



Publication:
"Flexible On-chip Inductors and Transformer", J. Wang, IMAPS Device Packaging Conf, Ft. McDowell, Arizona 10Mar10