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Additive Manufacturing of Precious Metals –
Challenges and Opportunities for Watch and Jewelry Applications

Swissphotonics Lab SNAP: Photonics 4 the European Industry of the Future
13/06/2018, Genève

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Outline

- Additive Manufacturing – a brief introduction
- AM of precious metals – state of the art
- Attempts to optimize the AM part quality
  - by optimizing the AM process
  - by optimizing the materials
- Summary

AM for jewelry and watch applications

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- Metal AM is a rapidly emerging technology based on the layer-by-layer consolidation of powder
- AM allows for the production of unique and one-of-a-kind parts with intricate geometries
- It is nowadays already applied on an industrial scale in e.g. aerospace, biomedical industry
- AM has been successfully used for jewelry, not so much for watches

/www.eos.info/
/www.scoop.it/

/C. Leinenbach, Photonics 4 the European Industry of the Future, Genève, 12.06.18/

Powder bed fusion – the principle

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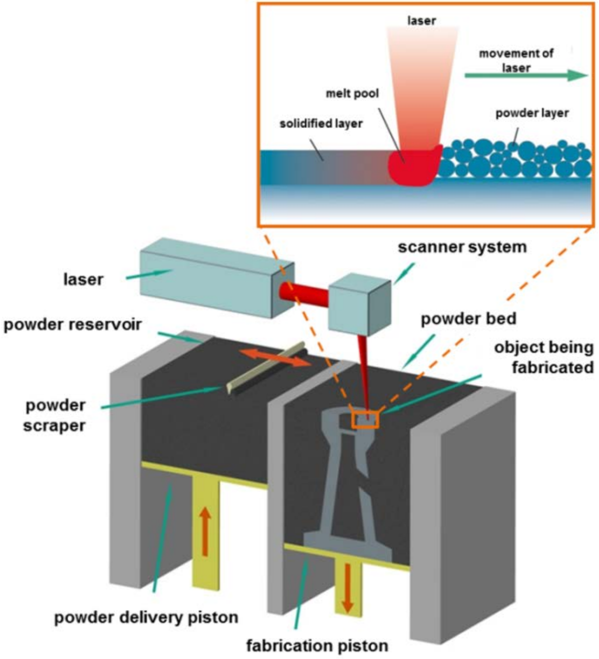
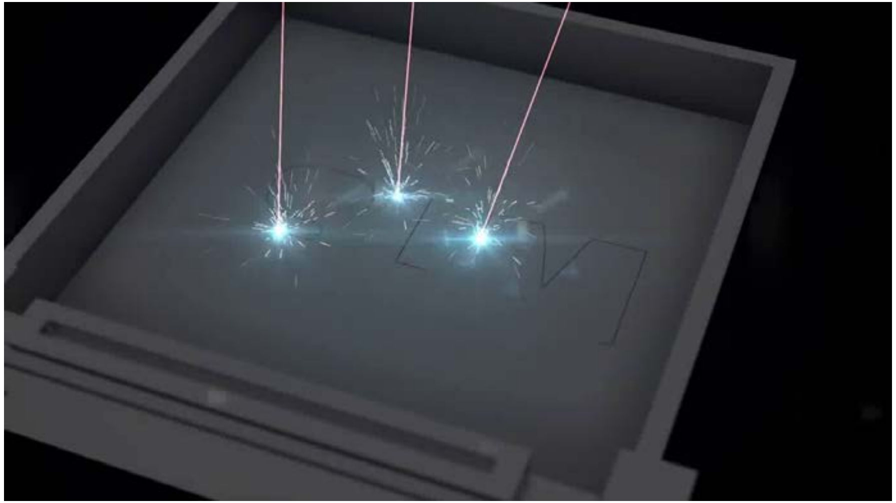
a.k.a Selective Laser Melting (SLM), laser cusing, laser sintering, laser metal fusion…



/Source: Fraunhofer IWU/



/Source: SLM Solutions/
https://www.youtube.com/watch?v=Mjf6oaMVWr8

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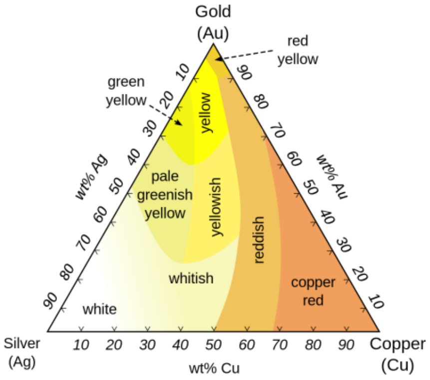
AM of precious metals

- Despite their high price, precious metals have been reportedly used for AM
  - 18K yellow (3N), rose (4N) and red gold (5N) alloys (Au-Ag-Cu)
  - Pt alloys (950 Pt/Ru, PtIr20, Pt-Au)
  - Pd alloys
- Dedicated powder bed AM machines with small build volumes and optimized powder recycling capabilities are available



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Typical defects in 18K standard gold alloys

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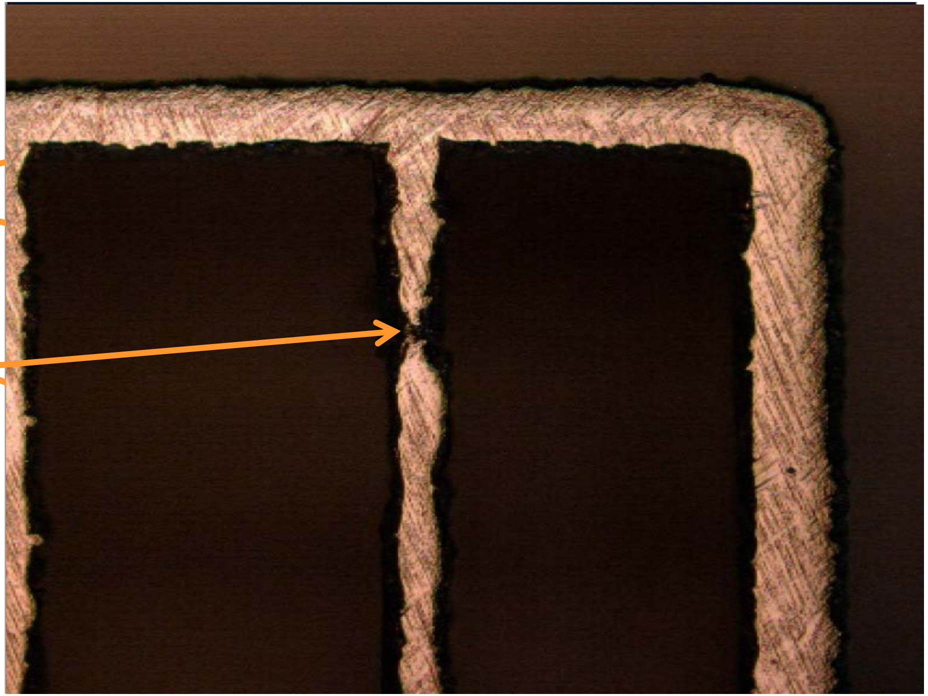
- Porosities
- Surface roughness
- Insufficient accuracy

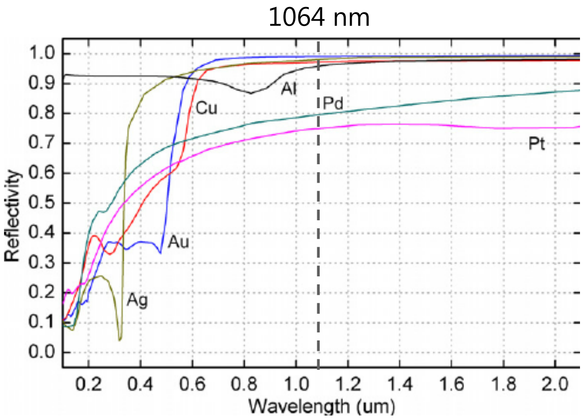


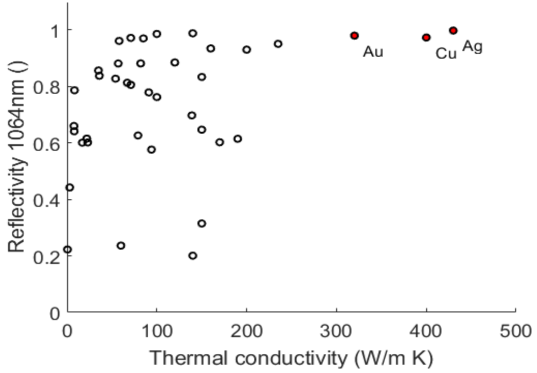
…a lot of post-treatment (grinding, polishing etc.) is required to make acceptable parts

Klotz, U. E., Tiberto, D., & Held, F. (2017). Gold Bulletin, 50(2), 111–121.
Zito, D. (2017). In *Proc. of Santa Fe Symposium on Jewelry Manufacturing Technology* (pp. 515–556).

Why are precious metals so difficult to process?

- High reflectivity
  - Almost 99% of the incoming laser light is reflected at 1064 nm
  - Only about 1% is absorbed and converted into heat
- High thermal conductivity
  - Au, Ag and Cu have the highest thermal conductivities among all metals
  - The heat induced by the laser spot is dissipated rapidly
- Pt and Pd are less difficult





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What can we control in the process?

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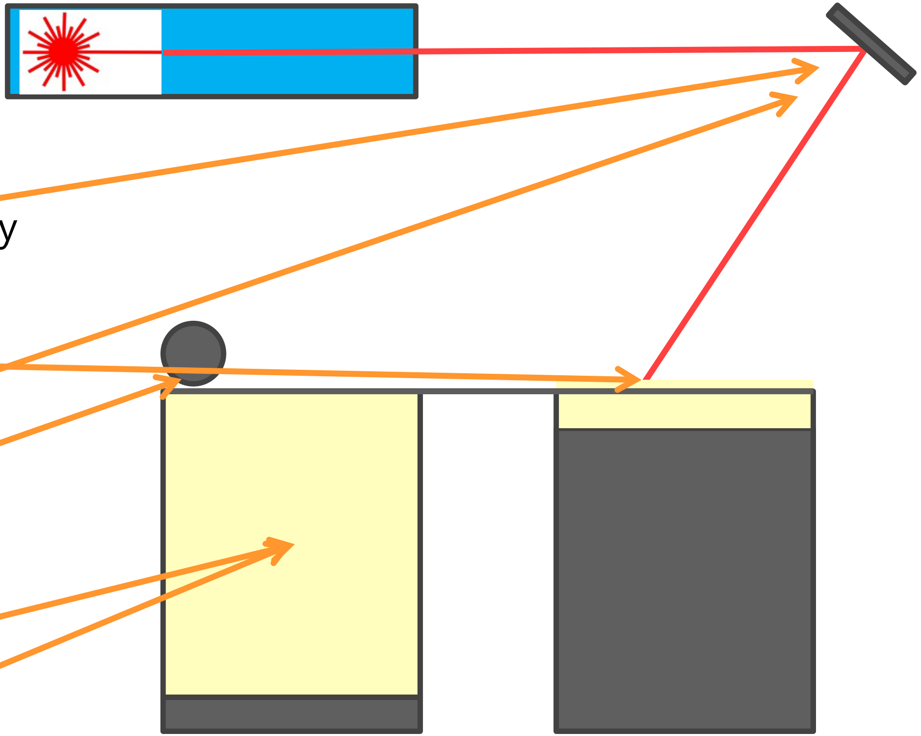
- Power, wavelength
- Scanning speed
- Spot size
- Scanning strategies
- Layer thickness
- Powder size and shape
- Material properties

Energy density



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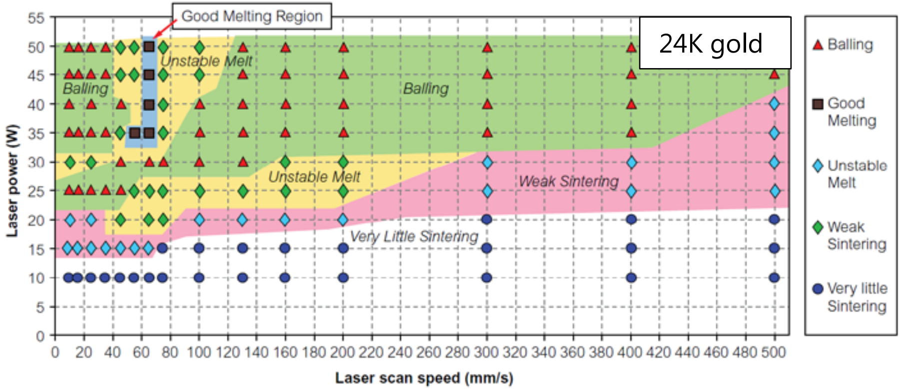
Optimizing the process parameters

- In general, the volume energy density is considered for process optimization

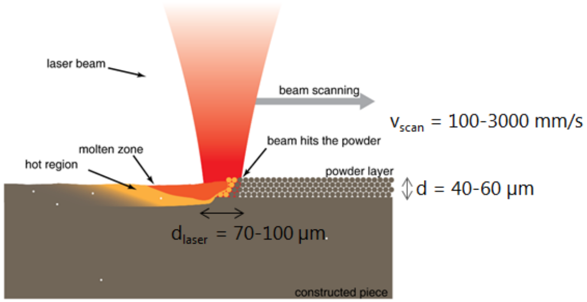
$$VED = \frac{P_L}{v_L \cdot h \cdot d}$$

P_L: Laser power, v_L: scan velocity
h: hatch distance, d: powder layer thicknes

- Systematic variation of P_L and v_L, while d and h remain constant
- For Au alloys, only a vary narrow parameter window was found

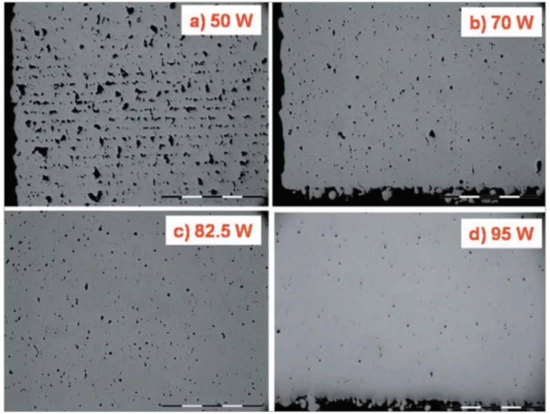


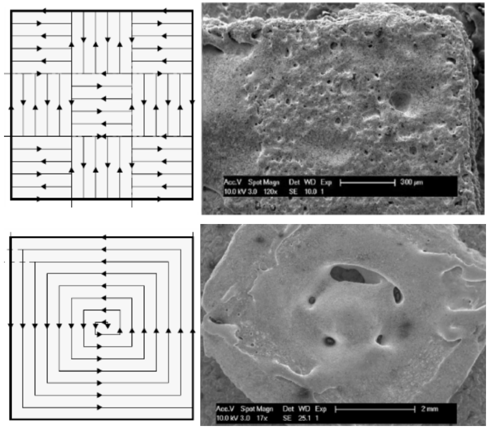
/Khan, M., & Dickens, P. (2010). Gold Bulletin, 43(2), 114–121./



Influence of laser parameters

- For Au alloys, the porosity can be reduced by adjusting the power or the scanning strategy, but it is still high compared to other metals
- With the scan strategy, the heat distribution can be changed in a certain range
- Still, the AM part quality is relatively poor after parameter optimization

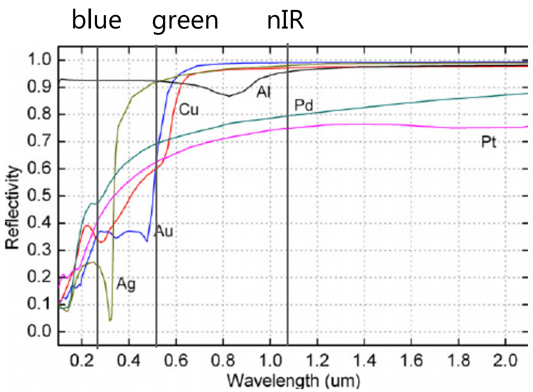




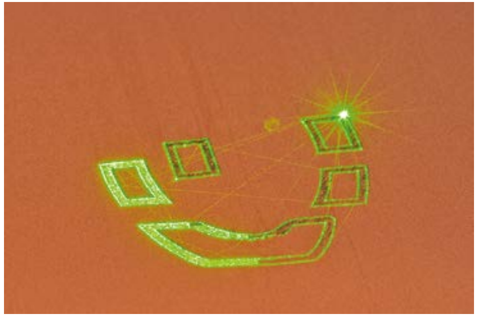
/B.J. Fischer-Buehner, et al.. (2012). In *Proc. of Santa Fe Symposium on Jewelry Manufacturing Technology* (pp. 177–202)/
/J. Jhabvala et al. *Virtual and Physical Prototyping*, 5(2), 99–109/

Use of lasers with shorter wavelengths

- The absorptivity of precious metals is increased at shorter wavelengths
- The use of green or even blue lasers in powder bed AM machines would be beneficial
- High power (>100 W) green and blue lasers are commercially available
  - First trials made on Cu with green laser, but they are still expensive
  - Blue lasers still have a rather poor beam quality



/Source: www.nuburu.com/



/Source: Fraunhofer ILT/

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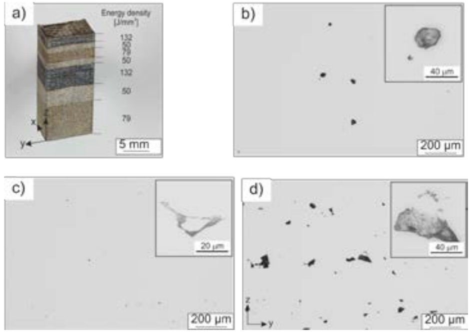
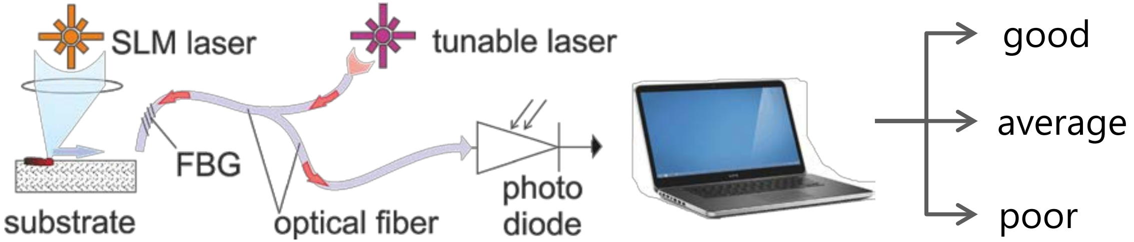
In situ and real time process monitoring

- In situ process monitoring and using acoustic emission during AM
- Defect detection in real time using machine learning approaches
- Detection reliability >85% demonstrated in first tests



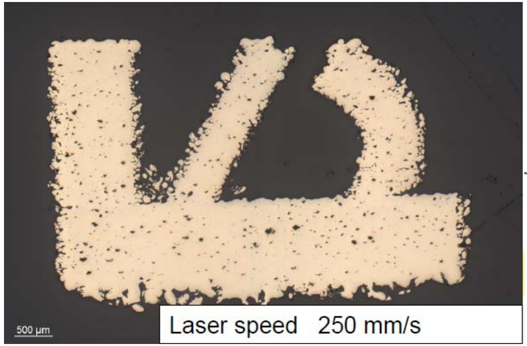


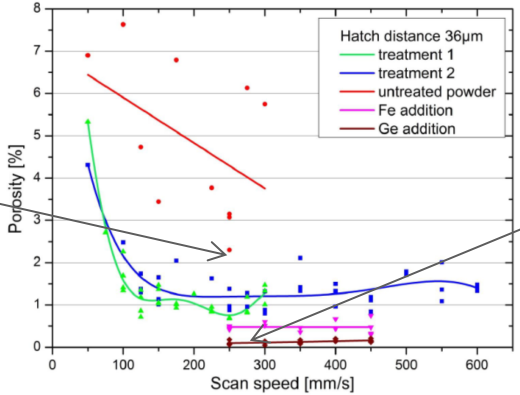
/S. Shevchik, C. Kenel, C. Leinenbach, K. Wasmer, Additive Manufacturing, 21 (2018) 598-604/

Modification of the alloy composition

- The thermal conductivity and the reflectivity of Au alloys can be influenced by small amounts of additional elements
- Microalloying with Fe and Ge could significantly reduce the porosity of yellow gold after AM
- Challenge: maintaining the color

untreated yellow gold powder





powder with Ge addition

/Tiberto et al., AAMS17, Dübendorf , 11/12 Sep 2017/

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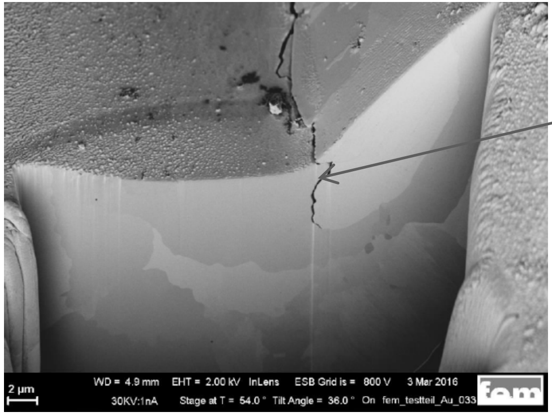
Modification of the alloy composition

- New problems: Hot cracking and brittle phases
- Ge is a pronounced melting point depressant
  - Wide melting interval 800-907 °C
  - Segregation Ge and formation of the film with even lower melting point
- Further research to understand materials behavior required



cracks

/Tiberto et al., AAMS17, Dübendorf , 11/12 Sep 2017/

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The PREAMPA project

PREcision Additive Manufacturing of Precious metals Alloys

- Multi-partner project within ETH domain (+ 8 industry partner) started in 2017
- Material development
  - Cataloguing precious metal alloys candidates for Selective Laser Melting (SLM), including metallic glasses and high entropy alloys
  - Alloying with trace elements
  - Sacrificial coating of metal powders
- SLM process development
  - Process optimization using two lasers with different wavelengths
  - In situ monitoring based on acoustic emissions for defects detection

Improving the processability of Au alloys

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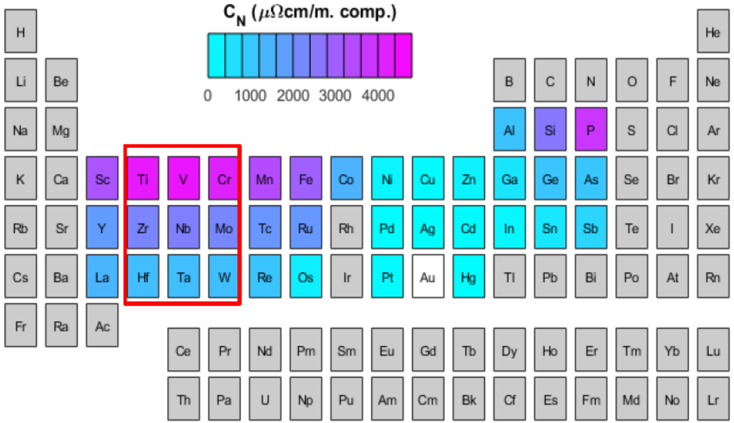
- A trial-and-error approach is not helpful
- Computational screening of potential alloying elements with regard to their influence on electrical and thermal conductivity.
- Ti, V and Cr are promising candidates
- Experimental validation in progress



$Au_{90}X_{10}$ – calculated with Munich SPR-KKR
Lattice parameter fixed @ 3.55 Å
impurity scattering

Summary

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- Metal additive manufacturing offers novel and hitherto unknown possibilities in terms of geometry and functionality of components
- In watch and jewelry making, it allows for the manufacture mof unique and one-of-a-kind customized parts
- AM of Au-alloys is challenging because of their physical properties (reflectance, thermal conductivity)
- Potential approaches to improve AM part quality
  - Optimization of process (shorter wavelength, process monitoring etc.)
  - Modification of material propertes

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Thank you!